AD-A118 558 TECHNION - ISRAEL INST OF TECH HAIFA CENTER OF HUMAN--ETC F/G 5/9
IMPROVING TIME-SHARING PERFORMANCE BY ENHANCING VOLUNTARY CONTR--ETC(U)
FEB 81 M BRICKNER, D GOPHER AFOSR-77-3131
UNCLASSIFIED HEIS-81-3 AFOSR-TR-82-0633 NL

AD A
118558

UNCLASSIFIED

AD A118558

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. Report Number AFOSR-TR- 82-0633 / 2. Govt Accession No. AD-A118 558	3. Recipient's Catalog Number
4. Title (and Subtitle) Improving Time-Sharing Performance by Enhancing Voluntary Control on Processing Resources	5. Type of Report & Period Covered INTERIM Oct. 1, 1979 - Sept. 30, 1980
	6. Performing Org. Report Number
7. Author(s) Michael Brickner, Daniel Gopher	8. Contract or Grant Number AFOSR-77-3131
9. Performing Organization Name and Address Research Centre for Work Safety and Human Engineering Technion - Israel Institute of Technology	10. Program Element, Project, Task Area & Work Unit Numbers 61102F 2313/A2
11. Controlling Office Name and Address Air Force Office of Scientific Research/NL Bolling AFB DC 20332	12. Report Date Feb 1981
	13. Number of Pages 94
14. Monitoring Agency Name and Address	15. Unclassified

16. & 17. Distribution Statement

Approved for public release; distribution unlimited.

DTIC ELECTE AUG 24 1982 D

18. Supplementary Notes

19. Key Words

20. Abstract Development of voluntary control on processing resources in concurrent task performance is studied within a training paradigm which attempts to identify the components of time-sharing skills. Two experiments are described in which subjects were trained under dual task conditions. In the first experiment three groups of subjects were trained in the concurrent performance of pursuit tracking and letter typing. One group practised under 5 different levels of inter-task priorities with augmented on-line feedback on performance. Another group received feedback augmentation but practiced only under equal priorities conditions. A third group was allowed to develop its spontaneous strategy with no feedback augmentation or priority manipulation. In the second experiment only the first two groups were contrasted in the joint performance of letter typing and digit classification.

continue/...

FORM 1473

UNCLASSIFIED

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

Experimental results demonstrated that training under variable priority conditions may lead to improved performance capabilities on several aspects of the time-sharing situation.

First, the general level of performance achieved by subjects trained under variable priorities was better than the levels reached by the other two groups at the end of training. Secondly, these subjects were better able to protect performance when task difficulty was varied. Finally, they revealed better ability to generalize their acquired skill to other time-sharing conditions that included a new task component.

These results are interpreted to indicate that human operators can actively control their resource allocation but appear to have limited knowledge or skill to insure the efficiency of their allocations. In the absence of relevant information spontaneous strategies may lead to sub-optimal solutions. Proper instruction may enhance the efficiency of voluntary control.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

AFOSR-TR- 82-0033

IMPROVING TIME-SHARING PERFORMANCE

BY ENHANCING VOLUNTARY CONTROL

ON PROCESSING RESOURCES

Michael Brickner Daniel Gopher

Technical Report AFOSR-77-3131

February, 1981

HEIS-81-3

Prepared for the Life Sciences Directorate of the United States Air Force Office of Scientific Research and European Office of Aerospace Research and Development.

Technion - Israel Institute of Technology

Faculty of Industrial Engineering and Management

Research Centre for Work Safety and Human Engineering

82 08 ... 009

This research was supported by the Life Sciences Program, Air Force Office of Scientific Research, under grant No. AFOSR-77-3131C. The report is based on a dissertation submitted by Michael Brickner in partial fulfilment of the requirements for a Doctor of Philosophy degree at the Technion - Israel Institute of Technology.

Dr. Genevieve Haddad at the Life Sciences Directorate and Major Christopher Lind of the European Office were the scientific monitors of this grant.

Thanks are due to Ron Clapman and Rachel Naveh for their programming efforts; to Nella Chillag for her help in the analysis of data and to Dr. Colin Kessel for his comments on an early version of this report.

ABSTRACT

Development of voluntary control on processing resources in concurrent task performance is studied within a training paradigm which attempts to identify the components of time-sharing skills. Two experiments are described in which subjects were trained under dual task conditions. In the first experiment three groups of subjects were trained in the concurrent performance of pursuit tracking and letter typing. One group practised under 5 different levels of inter-task priorities with augmented on-line feedback on performance. Another group received feedback augmentation but practiced only under equal priorities conditions. A third group was allowed to develop its spontaneous strategy with no feedback augmentation or priority manipulation. In the second experiment only the first two groups were contrasted in the joint performance of letter typing and digit classification.

Experimental results demonstrated that training under variable priority conditions may lead to improved performance capabilities on several aspects of the time-sharing situation.

First, the general level of performance achieved by subjects trained under variable priorities was better than the levels reached by the other two groups at the end of training. Secondly, these subjects were better able to protect performance when task difficulty was varied. Finally, they revealed better ability to generalize their acquired skill to other time-sharing conditions that included a new task component.

These results are interpreted to indicate that human operators can actively control their resource allocation but appear to have limited knowledge or skill to insure the efficiency of their allocations. In the absence of relevant information spontaneous strategies may lead to sub-optimal solutions. Proper instruction may enhance the efficiency of voluntary control.

IMPROVING TIME-SHARING PERFORMANCE BY ENHANCING VOLUNTARY CONTROL ON PROCESSING RESOURCES

Michael Brickner, Daniel Gopher

Technion - Israel Institute of Technology

Haifa, Israel

INTRODUCTION

In the present report we address some basic issues related to the training of time-sharing skills. More specifically, development of voluntary control on processing resources is investigated within a training paradigm. It is argued that attention control is a trainable skill which improves and becomes more efficient with training. Concepts and tools from the areas of skill acquisition and attention processes are combined to study the nature of this skill and the proper procedures for its development.

Attention and Skill

When an unpracticed operator attempts to perform two or more complex tasks concurrently, performance of at least one task usually suffers. Contemporary theories in cognitive psychology view information processing and response capabilities as constrained by the limits of attention. Three main theoretical approaches can be distinguished: a) structural models: these models assume that performance is constrained by the rate of processing of one central or several processing mechanisms. These mechanisms create a "bottleneck" for any highly demanding task (Broadbent 1958; Treisman 1969; Welford 1968; 1978); b) capacity models: these approaches postulate the existence of a single central pool of processing resources. Performance is argued to suffer when the supply of resources does not meet

the sum of demands of the concurrent tasks (Kahneman 1973; Norman and Bobrow 1975; Posner and Bois 1971); c) finally, integration of these approaches is proposed by the multiple resource models: these most recent approaches claim that the human operator possesses a number of processing mechanisms each having its own capacity (Navon and Gopher 1979; Wickens 1980). Thus, the effects of resource scarcity on concurrent performance depend on the extent to which the tasks involved compete for common resources.

Both everyday experience and laboratory research indicate that performance decrements observed in concurrent task performance may gradually disappear when the individual is given more practice on the tasks, even if the initial impairment is severe (e.g., Underwood 1974; Ostry, Moray and Marks 1976; Spelke, Hirst and Neisser 1976; Gopher and North 1977; Logan 1979). However, none of the above-mentioned models of attention has systematically treated the effects of practice. What happens when a novice unpracticed operator becomes skilled or well trained? How does learning affect the limited capacity mechanisms? Investigators of attention have generally ignored the process of skill development when attention mechanisms are concerned, and usually preferred to investigate relatively simple task situations which do not require an extensive amount of practice. Schneider and Shiffrin (1977) complain that a vast majority of the literature on human performance, and arguments about human capacity, are based on the results of poorly practiced and relatively unskilled subjects.

In recent years, several attempts have been made to examine sources of performance improvement under time-sharing performance combining concepts from theories of skill acquisition and the study of attention processes. Gopher (1980) discusses three categories of factors that can account for improved performance with practice in concurrent task situations:

a) The demand for resources of each task is reduced.

b) Coordination between tasks is enhanced.

c) Improved voluntary control on resources enables increased efficiency of resource utilization.

In the following sections these factors are discussed in detail and some related topics are elaborated upon.

Reduced demand for resources

With sufficient practice, less resources are required by each of the tasks in the concurrent task situation. Thus, the total amount of resources required for performance is reduced. Some authors claim that with prolonged and consistent training, a task may be performed automatically, with minimal demand for central resources (Posner and Snyder 1975; Schneider and Shiffrin 1977; Shiffrin 1975; Logan 1978, 1970). Improved efficiency in the performance of each task in a multiple task situation may undoubtedly reduce the overall resource demands of concurrent task performance. However, several sources of experimental evidence show that this reduction may not be the sole factor. For example, some tasks are harder to automatize and improve very little with training (see, e.g., varied mapping - Shiffrin and Schneider 1977). In addition, evidence from a number of studies indicates the existenceof one or more factors which are relevant only to the time-sharing situation as a whole, such as coordination (Logan 1979) and interweaving strategies (Gopher and North 1977).

These factors were usually referred to as "time-sharing ability" or "time-sharing skills". The term "ability" is usually employed to imply a fairly consistent and enduring performance capability, while "skill" refers to a more temporary capability that is developed with practice. The exact distinction between these two terms has not always been recog-

nized in the experimental literature. In the present work we shall be primarily concerned with the acquisition and nature of time-sharing skills.

Is there a general time-sharing skill? One of the basic issues in the effort to assess the nature of time-sharing skills is whether these skills are common to all or to many types of concurrent task situations, or specific and task-dependent?

In one of the earliest studies in this area, Bahrick and Shelley (1958) trained their subjects in the performance of two different choice reaction-time tasks, one visual and one auditory. They observed that at the end of the second experimental session, subjects reached their maximal performance level on each task by itself. But, improvement on both tasks in joint performance continued for several additional sessions. Similar results were obtained by Kalsbeek and Sykes (1967) with two binary choice reaction-time tasks, and by Gopher and North (1977) in the concurrent performance of tracking and digit processing. These results clearly indicate that performance capability of dual tasks is more than just the sum of improved performance on each task element by itself.

Several attempts were made to identify the common denominator underlying the improved time-sharing performance of various complex task configurations (e.g., Fleishman 1965; Freedle, Zavala and Fleishman 1968; Sverko 1977; Damos 1977; Jennings & Chills, 1977; Hawkins, Rodriguez and Gerald, 1979; Rieck, Ogden and Anderson 1980). Two main experimental paradigms have been employed in these attempts:

a) Correlational approach, in which correlations between performance measures in various combinations of tasks were compared in order to determine the relative contribution of task specific versus more general time-sharing factors. Sometimes factor analysis techniques

were used in an attempt to identify a time-sharing factor, common to several different dual or triple task configurations.

b) Training and transfer studies - in which the effects of practice in one time-sharing condition on the performance of another time-sharing condition were studied to evaluate the amount of transfer due to improved "time-sharing capabilities".

Correlational studies: Fleishman (1965) developed an experimental task which simulated the control of role, heading and velocity of an aircraft. Two hundred subjects practiced each task element separately, all dual task combinations and the three tasks together. Correlation coefficients between all dual task performance measures were higher than those obtained between each dual task component and its single task measure. Using a multiple regression equation, Fleishman found that dual task scores predicted performance on the triple task situation better than any combination of the three single task scores. These results were interpreted to indicate the existence of a general time-sharing skill. It should be noted that all task combinations compared by Fleishman had at least one task in common. Hence, contributions of the "general time-sharing" factor cannot be truly separated from task specific factors.

Sverko (1977) had his subjects practice four tasks: pursuit rotor tracking, digit processing, mental arithmetic and auditory discrimination. Each task was performed singly as well as in all six possible dual-task combinations. Factor analysis failed to reveal any general time-sharing factor in dual task performance.

Jennings and Chiles (1977) tested 39 subjects in six tasks. Each task was performed separately and then in combination with two other tasks, thus creating two complex triple task situations composed of three task

subsets. Factor analysis of the performance data revealed one factor that had high loading on two different monitoring tasks - only under time-sharing conditions. The same two tasks had no significant common factor when performed singly. No other common, time-sharing factor was revealed.

Hawkins, Rodriguez and Gerald (1979) studied the performance of subjects in eight dual-task conditions. Three aspects of tasks were varied: input modality (auditory or visual), output modality (manual or vocal) and task difficulty (easy or difficult). In general, higher correlations were obtained between conditions that had common task characteristics. The authors conclude that time-sharing performance is largely determined by several task-specific subcapacities rather than by a single, general capability or ability.

Transfer of training studies: Freedle, Zavala and Fleishman (1968) studied performance in a triple task condition employing the same flight simulation apparatus used by Fleishman (1965) (see previous section). They found that the triple task was performed better after initial practice period in dual task combinations, than after practicing each task separately. In a subsequent study, Zavala and Geist (1968) failed to replicate these results.

Damos (1977) gave 65 subjects practice on a memory task and a digit classification task. Half of her subjects performed each task separately while the other half performed them together. On the following day all subjects performed two tracking tasks simultaneously. The results showed only very small differences in favor of the dual-task group. Statistical significance was achieved only after the results of 26 subjects, who did not reach satisfactory performance levels, were eliminated.

Rieck, Ogden and Anderson (1980) contrasted the effects of initial

single or dual task training and the similarity of tasks on the subsequent performance of a dual task. Subjects in the single-task group practiced a uni-dimensional discrete compensatory tracking task. Subjects in the dual-task group performed the same task simultaneously with a digit classification task. Both groups were transferred first to a "similar" dual-task situation, consisting of a discrete tracking and a delayed recall of digits, and then to a "different" dual-task situation, consisting of a continuous tracking task and a self-paced choice reaction-time task. The authors report that the initial amount of dual-task training had a significant effect on dual-task performance of the "similar" task, while single task training had only negligible effects on that task. Performance of the "different" dual transfer task did not differ between the groups.

The outcomes of both correlational and transfer of training studies lead quite clearly to similar conclusions. Studies which investigated correlations or transfer of training between similar or identical tasks yielded strong evidence to the existence of a time-sharing factor, over and beyond single task improvement (Fleishman 1965; Freedle, Zavala and Fleishman 1968; Hawkins, Rodriguez and Gerald 1979; Rieck, Ogden and Anderson 1980). In contrast, studies which attempted to reveal correlations, common factors or transfer of training between different types of tasks, produced mostly negative or non-conclusive evidence (Sverko 1977; Damos 1977; Jennings and Chiles 1977; Reich, Ogden and Anderson 1980).

It appears justified to summarize this brief reveiw of research by saying that while the general notion of the existence of a time-sharing factor has been supported, it also appears that its generality is restricted and tied to the specific tasks involved in the time-sharing situation. The exact nature of this tie which simultaneously allows independence and dependence of the acquired time-sharing skill from its task composites is

still to be determined in future investigation.

Coordination between tasks: Improved coordination between tasks in concurrent performance is one possible interpretation to an element of time-sharing skill that is both task specific and can only be developed with practice under time-sharing conditions. One view on the nature of coordination is that it constitutes a task by itself and thus consumes supervisory and control resources (Moray 1967; Logan 1979). With practice, through automotion (Logan 1979; Shiffrin and Schneider 1977) or established S-R mapping (Moray 1967), the cost of coordination is reduced and more resources become available to the direct performance of the tasks. Some authors have even argued that with prolonged practice coordination may develop into integration, in which the former separate tasks create a new whole. This new whole demands less resources than the concatenation of the resource demands of its former elements (Neisser 1976).

Gopher and North (1977) and Navon and Gopher (1979) present a somewhat different interpretation of the coordination process. They argue that coordination of tasks may not require resources by itself. However, poor coordination results in inefficient utilization of processing resources. Coordination improves the returns of resources investment.

Navon and Gopher (1979) interpret task coordination within the framework of their theory of multiple resources. According to this conceptual framework, the human processing system possesses several limited capacity mechanisms, and tasks may only partially overlap in their demand for common resources. If different resources can partially substitute for one another (for example trading visual intakes and memory representations in a reading task) alternative combinations of resources may be employed for the performance of the same task. When different tasks are performed

together, resources may be allocated such that overlapping demands for the same resources are minimized. If such a strategy is successfully adopted, concurrent performance of tasks will not suffer from resource scarcity.

Voluntary control on resource allocation

Another way in which performance under time-sharing conditions may improve with practice is by improving the voluntary control a subject has over his processing resources. Most contemporary theories of attention view the process of selective attention as a dynamic, active process influenced by motivation, utility considerations and voluntary strategies (e.g. Kahneman 1973; Navon and Gopher 1979).

Gopher (1980, note 1) identifies three major questions concerning the voluntary control of attention resources:

a) What is the extent of voluntary control on resources?

b) Does this ability develop with practice?

c) Is the human operator an optimal allocator?

These questions have generally been overlooked in the investigation of attention processes and completely neglected in the study of acquisition of complex performance skills.

Most researchers in these fields have assumed good voluntary control on resource allocation. Thus, it is implicitly postulated that with a sufficient amount of practice every human operator will reach an optimal strategy of resource allocation.

In the following section this assumption is examined in the light of experiments in which manipulation of resource allocation was conducted.

Resource allocation between tasks in dual-task experiments

Dual-task studies most commonly use secondary task techniques. Under this paradigm subjects are required to perform two tasks such that the performance of one task (primary task) is protected. Secondary task performance is allowed to improve only as long as performance on the primary task is not affected.

The question is to what extent can subjects comply with this instruction? Some authors assumed full compliance, and did not even find it necessary to report the level of performance on the primary task (Michon 1966; see also Rolfe 1971, pp. 144-145 for a review of other research). However, a large number of studies showed that the addition of a secondary task caused a significant decrement in primary task performance. Ogden, Levine and Eisner (1979), in a review of the post-1965 literature on the measurement of workload by the secondary task technique, reported a decrease in performance of the primary task, in about one-third of the 146 articles reviewed. Such a decrease occurred when the secondary task was introduced, when the difficulty levels of either task were manipulated, or both.

For example, Wickens (1979) had his subjects perform two identical one-dimensional, compensatory tracking tasks. One was defined as primary and the other as secondary. Subjects were instructed to maintain a constant level of performance on the primary task. When the difficulty of this task was increased, performance on both primary and secondary tasks deteriorated. In a second experiment an easier version of the primary tracking task was used. In this case subjects were able, after four days of practice, to protect primary task performance and maintain a constant performance level despite the difficulty manipulation of this task. However, protection was not achieved at the cost of secondary task perform-

ance, which remained constant. Addition of on-line feedback on performance did not alter these results. Thus, it appears that the problem did not stem from difficulties in the identification of task demands but from subjects' inability to shift their resources from the secondary task to improve performance on the primary tracking task.

A more direct assessment of voluntary control on resource allocation has been conducted in several experiments in which the priorities of tasks were varied under dual task conditions. Woodhead (1966) observed an asymmetric effect of task emphasis manipulation on the joint performance of a difficult memory task and an easy search task. Performance on the memory task improved when it received higher priority levels (manipulated by verbal instructions), while performance on the search task was indifferent to priority levels. Because difficulty and type of task were confounded in this experiment, the causes of this asymmetry cannot be determined.

Johnson, Griffith and Wastaff (1972) manipulated priorities by changing momentary payoffs. They found that performance levels on a memory task and a reaction time task were altered as a function of their relative payoffs.

Sperling and Melchner (1978a, 1978b) used a visual search task, in which digit had to be identified within letter arrays. They instructed their subjects to search for two targets, each embedded in one or two different arrays presented simultaneously, one at the center part of the display, the other in a square surrounding it. Subjects were required to identify and report the location of targets. They were instructed to divide their attention in various proportions between the two arrays. It was found that the higher the priority of an array, the better the detection of numerals in this array and vice versa.

One of the major problems in the evaluation of resource allocation on performance is that experimenters have no direct control over the way subjects allocate their resources. They can try to influence resource allocation by telling subjects how to do it. When this is done by verbal instructions, as in the above-described studies, the experimenter assumes that the subjects are both sensitive enough to detect deviations from optimal behavior, and have good control on their processing devices to carry out the desired changes. Thus, when behavior is not optimal, it is impossible to determine whether deviation from optimality results from a lack of sensitivity, insufficient control on processing resources, or both.

A more advanced technique to manipulate task priorities under dual-task conditions was developed by Gopher and North (1974). The technique is based on an on-line dynamic display of the differences between actual and desired performance in each of two concurrently performed tasks. Desired performance is determined relative to subject's maximal level of performance obtained in an early adaptive training period. In one study of the concurrent performance of a one-dimensional tracking task and a choice reaction time task, Gopher and North (1974) employed two short static horizontal lines displayed on both sides of a CRT screen to represent the desired level of performance on each task. In addition, continuously, vertically moving bargraphs represented momentary differences between actual and desired performance on those tasks. Changing the location of the desired performance lines (which corresponded to a required level of performance on that task) enabled the experimenter to alter the relative priorities of the tasks. The use of such a technique reduces the problem of lack of sensitivity of a subject to deviations from optimal performance and is therefore very useful in the investigation of voluntary resource allocation. This experimental technique was since applied in several studies

of complex task performance. In all studies significant effects of priority on performance were obtained for a variety of experimental tasks (Gopher and North 1974; Gopher and Navon 1980; Gopher and North 1977; Wickens and Gopher 1977; Gopher, Brickner and Navon, in press). These findings indicate that the experimenters have succeeded to influence the allocation policy of their subjects.

A close examination of the effects of priority manipulation on concurrent performance reveals some interesting results. For example, North (1977) found that the overall joint performance of two compensatory tracking tasks was most efficient when both tasks were performed with equal priorities. Any deviation from the equal priority condition resulted in a big drop in combined scores of performance efficiency. When tracking was performed with a digit classification task he found that digit classification was sensitive only to changes in its own performance demands and indifferent to changes of demands on the tracking task.

Gopher and Navon (1980) conducted a series of three experiments in which each of the dimensions (vertical and horizontal) in a dual axis pursuit tracking task was treated as a separate task. For each axis of tracking, priorities and difficulty levels were manipulated. In the first experiment, in which task difficulty was manipulated by varying the frequency of target movement, priority manipulation had a large effect on performance. However, these effects were negatively accelerated and combined performance was most efficient in the condition of equal priorities. Subjects reduced their performance level on a task when its priority was lowered but performance on the other task, on which priority levels were simultaneously increased, was not enhanced beyond the level that was achieved under the equal priority conditions. The same pattern of results repeated in the second experiment, when task difficulty was manipulated by

varying the velocity of target movements. In the third experiment, task difficulty was increased by manipulating control dynamics. In this case lowering priority on one task led to improved performance on the other high priority task. But, the overall effects of priorities in this experiment were small as compared with the magnitude of their effect in the first two experiments.

Several interpretations can be offered to account for these findings:

a) Decrease in marginal efficiency of resources: When a task becomes more difficult the marginal efficiency of resource investment in it is decreased (Navon and Gopher 1979). This means that the investment of a unit resources will yield larger improvement in an easy than in a difficult task. At the point where the marginal efficiency of resources approaches zero, a task will benefit very little from resources released due to reduced performance on a concurrently performed task. The task is approaching its data limitation (ceiling effect) (Norman and Bobrow 1975, 1976).

Effects of increased priorities can be analyzed in a similar way. When priorities on one task are increased the subject is expected to invest more resources to improve performance. However, the returns of this investment diminish rapidly when performance approaches its scale limit. Thus, when performance-resource functions are negatively accelerated, decrement in performance on the task on which priorities were decreased are expected to be larger than the improvement on the task on which priorities were increased, leading to a deterioration in the combined performance scores.

In the study of Gopher and Navon (1980), the reduced marginal efficiency of resource investment in a high priority tracking task was

clearly demonstrated. In the first of the three experiments it seems as if performance was data limited. Namely, performance on each task improved very little beyond the level of equal priorities. However, further analysis and manipulation of task difficulty indicated that these findings were not the result of a data limitation. Data limitation should be more apparent on an easy than on a difficult task. Such a differential effect was not found by Gopher and Navon.

b) Interference due to the requirement to divide resources in unequal shares: When different tasks are concurrently performed without specific instructions regarding the relative priorities of tasks, subjects are likely to balance their investments on the two tasks or follow some spontaneous performance strategy. Instructions to allocate resources in different proportions may constitute a task by itself and consume resources (Logan 1979; Moray 1967). Hence, it may compete with the resource demands of the concurrently performed tasks and lead to performance decrements in every deviation from natural or spontaneous strategies. Gopher, Brickner and Navon (in press) investigated the concurrent performance of tracking and a letter typing task with manipulation of priorities and real-time feedback indicators. They report that subjects' ability to comply with changes of task priorities improved considerably with practice. This evidence supports the argument that the ability to reallocate resources can indeed constitute a skill by itself.

c) Single capacity or several resources: Performance tradeoffs between tasks as a result of priority manipulation would only be revealed in tasks which compete for a common pool of resources. If tasks can draw on separate resources as proposed by the multiple resource approaches (Navon and Gopher 1979; Wickens 1980), one task cannot benefit from resources released by the other task.

Gopher and Navon (1980) concluded that the vertical and horizontal tracking tasks employed in their first two experiments did not compete or competed very little with each other for common processing resources. In the third tracking experiment where difficulty was manipulated by varying control dynamics, such competition was revealed and attributed to sharing of a common motor-related resource. Their conclusion was further strengthened by a subsequent finding that when the tracking tasks of their first experiment were performed simultaneously with a digit classification task, digit performance and tracking accuracy were similarly affected when the digit task was paired with a single axis or a dual axis tracking task (Navon, Gopher and Chillag 1980).

Neither a marginal efficiency interpretation or a multiple resource approach can account for the findings of Wickens' (1979) experiment discussed earlier. To recall, Wickens had his subjects perform two identical horizontal compensatory tracking tasks, one defined as primary, the other as secondary. When the average difficulty of the primary task was high, subjects were not able to protect its performance when difficulty was manipulated. If an easier primary task was employed, subjects succeeded in maintaining a constant level of performance after sufficient practice. Protection was not achieved at the cost of reducing secondary task performance. Thus, it appears that there was no resource tradeoff between the two tasks, in spite of their identity, which excludes the argument that separate resources have been used. It is also clear that the tasks were not data limited because performance of both improved monotonically with practice in the dual-task situation.

One possible interpretation to the independence of performance on the two tasks is subjects' inability to identify deviations of actual from required performance. A second possibility is a control problem,

i.e., inability of subjects to mobilize resources from one task to the other to meet performance demands. Wickens (1979) found that the use of on-line feedback indicators which should eliminate most difficulties of identifying deviations from optimality did not alter the pattern of results. Therefore, insufficient control over processing resources appears to be a more plausible interpretation of his results.

It is with this possibility that the present work is primarily concerned.

d) The extent of voluntary control on processing resources: Most theories of attention and skill acquisition seem to assume (at least implicitly) that the human operator has good control over his processing resources. Sufficient practice time and consistency of training conditions were most frequently assumed to be the only necessary requirements for the development of efficient resource allocation in the performance of complex tasks(e.g.see Hirst et al 1980; Schiffrin and Schneider 1977). In the previous section we have already shown that this assumption may not be justified and that in many cases performance deviates significantly from optimality. Such deviations are most salient when unbalanced priorities are assigned to concurrently performed tasks (North 1977; Gopher and Navon 1980; Navon, Gopher and Chillag 1980). Some explanations to the data observed under these conditions were already discussed in the previous section. However, these interpretations cannot account for all findings (e.g., Wickens 1979). An additional factor that cannot be ignored is the extent of voluntary control on processing resources.

If it is accepted that attention control is a complex skill acquired with training, there is no reason to assume that prolonged practice time is the only requirement to assure most efficient acquisition of this skill. It has long been recognized that different schedules of

learning and training strategies may affect the acquisition process or final levels of psychomotor or verbal skills (e.g., part-whole training, Adams and Hufford (1962); use of feedback and knowledge of results, Holdings (1965)). In an analogous way it seems justified to look for the most proper way to develop and teach the skill of attention control (Gopher 1980, note 1).

When two tasks are performed simultaneously with fixed priority levels it may not be too difficult to develop an effective strategy of performance and resource allocation. If, however, various priority combinations are required, the operator needs to acquire some internal representation or "internal model" of his processing system to determine the functional relationship between resource investment and performance.

An "internal model" of resource allocation

The internal model concept has been used as a major hypothetical construct to describe the interaction of human operators with complex systems. This concept signifies a number of engineering modelling approaches which are mainly based on control theory formulations. For example, the quasi linear models of Veldhuyzen and Stassen (1976), or Pew (1974).

Veldhuyzen and Stassen (1976) define the internal model as the "internal presentation of the knowledge the human operator has" (p. 158). They discuss the usefulness of the internal model concept in the description of human control of engineering systems and conclude that "the study of the meaning of the internal model concept is of great importance in understanding human performance because the monitoring decision-making, predicting or extrapolating and planning activities of human beings are all based on an internal model" (p. 159).

In the present context, an internal model of processing resources should be examined in light of two basic questions. One is the process by which it develops under different conditions of interaction. Another is the way in which such a model may affect performance in a particular time-sharing condition. Both questions are relevant to the study of attention control.

In the following section, a preliminary description of a possible internal model of resource efficiency in concurrent performance is presented. This scheme draws on concepts proposed by Navon and Gopher (1979). To better comprehend the model, some basic concepts from Navon and Gopher (1979) article are briefly reviewed.

In their analysis of the economy of the human processing system, these authors suggest that at any moment the human system can be conceived to possess a finite amount of processing resources. For an individual at a certain moment a task can be characterized by several parameters, e.g., stimulus-response compatability, signal-to-noise ratio, availability of relevant memory codes, etc. These characteristics are jointly termed subject-task parameters. If subject-task parameters are held constant, performance can be described as a function of the amount of resources invested in it and their efficiency. Such a function was labelled performance-resource function (PRF). For a given configuration of subject-task parameters, the amount of resources required to achieve a certain level of performance may be derived from the PRF and this quantity was termed demand for resources. The system is assumed to supply resources to meet demand to the extent that they are available.

When two tasks are performed simultaneously their joint performance would be a function of the resources allotted to each of them. For a given configuration of subject-task parameters, some levels of joint

performance are feasible and some cannot be achieved. The set of all performance combinations that can be produced when the system operates at its full capacity can be represented as a curve previously termed by Norman and Bobrow (1975) Performance Operating Characteristics (POC). A POC traces the bounds of joint performance with full capacity, all performance combinations that are on the POC or on the area enclosed by it, are feasible dual-task combinations. The effects of difficulty on dual-task situations can be described by constructing a family of POCs, in which each POC represents one level of task difficulty (Navon and Gopher 1980; Gopher and Navon 1980). Different types and shapes of POC families are discussed in detail by Navon and Gopher (1979, 1980).

In a typical dual-task experiment, subject task parameters are held constant, at least within trial, and certain performance demands are set either by verbal instructions, payoff matrix or real time graphic display, as described earlier. To maximize the returns of their resource investment subjects are required:

a) To detect deviations from optimal behavior

b) To be able to reallocate and mobilize resources to regain optimality (Gopher 1980, note 1).

Accomplishment of these tasks requires the development of a good internal representation of the performance-resource function (PRF) of each task and the resulting POCs. Development of such representation may be a sufficient condition to detect deviations from optimal allocation, but mobilization and reallocation of resources may require additional skills not directly related to this model. Figure 1 depicts a hypothetical performance resource model for task X and task Y.

In the upper right section the POC for the performance of two tasks

(Px, Py) is plotted. The upper left and lower right sections depict the performance-resource functions for each of the two tasks. The allocation

---

Insert Figure 1 about here

---

policy line in the lower left section describes the variation in the amount of resources allocated to each task. Points a, b and c on this line describe the results of different allocation policies on the performance of each task and joint performance.

When a subject is instructed to jointly perform tasks x and y at a certain priority level, he is actually expected to internally conceptualize both PRFx and PRFy (or similar representations) and divide resources such as to maximize joint performance, considering marginal efficiency and overlap of tasks in the demand for resources. Note for example, that PRFx in Figure 1 is almost linear, while PRFy is negatively accelerated. Thus, increasing the resource share of task x would yield the same amount of performance improvement across the whole range of task x performance, while the marginal efficiency of resource investment in y diminishes rapidly to the left of point b. If an operator selects to allocate the resource at the proportion marked by point c, he could achieve only little improvement in the performance of y at a cost of a large decrement in performace on task x.

It is evident that the internal model should change when different difficulty manipulations are applied or different pairs of tasks are combined. Possible variations in internal models are already large, even when a single capacity model is considered. With a multiple resource approach, the situation is further complicated. Recruitment of resources to meet a performance criterion may consist of combinations in various amounts of different processing resources, which may partially substitute for each other (Navon and Gopher 1979).

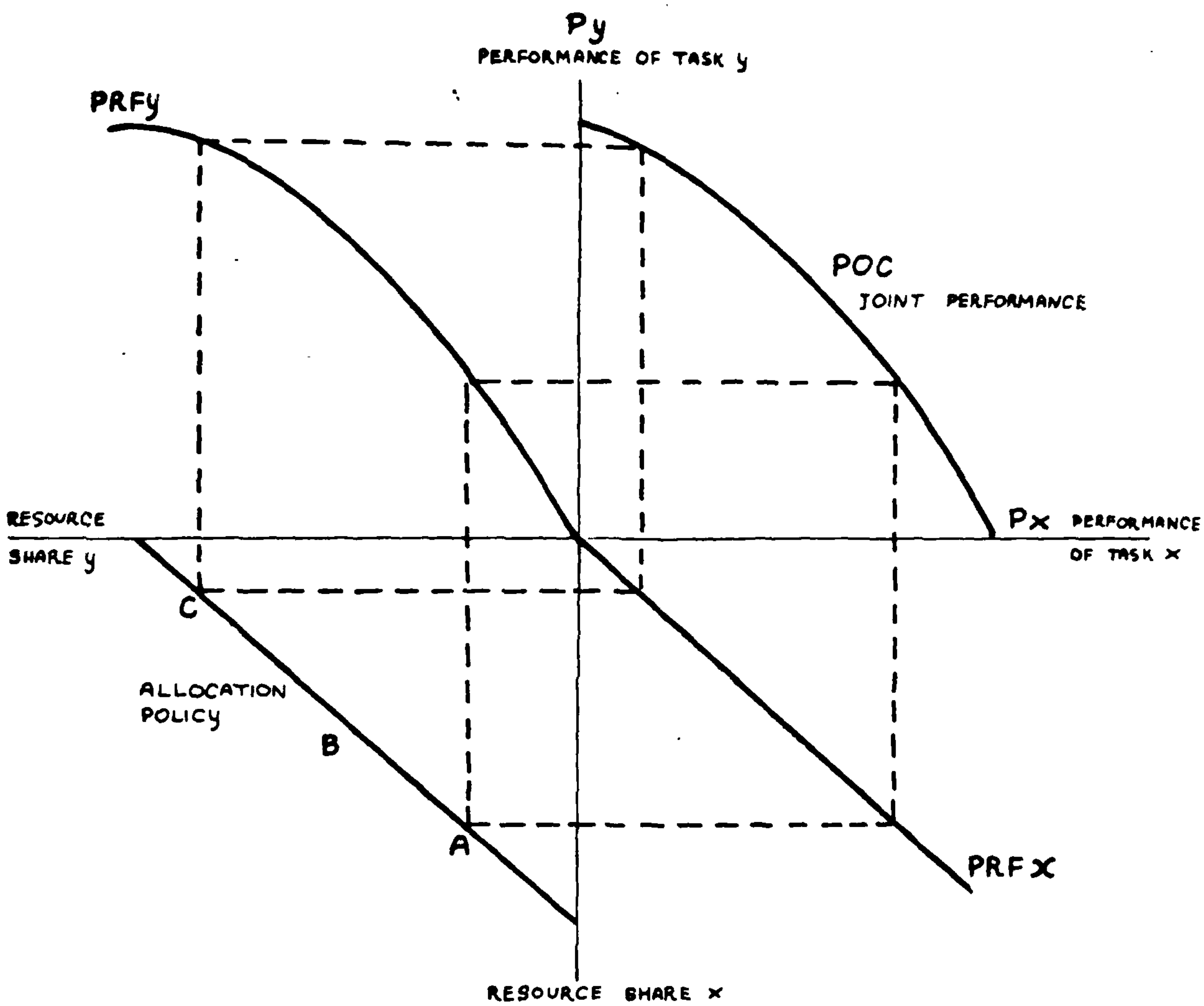


Fig. 1: A schematic representation of the relationship between the performance resource functions (PRF) of tasks x and y and their joint performance characteristics (POC).

The experimental work reviewed earlier demonstrated that manipulation of task priorities usually has a significant effect on concurrent task performance. However, operators' ability to detect deviations from optimal behavior and the extent of voluntary control on resources were not investigated systematically. Furthermore, the development of these capabilities with training was not assessed.

In a study of failure detection in dynamic systems, Kessel and Wickens (1978) and Wickens and Kessel (1979, 1980, 1981) showed that different methods of practice result in the development of different internal models which in turn were reflected in operator performance. In an analogous way, different practice strategies may have different impacts on the internal model of resources and the ability to use them under time-sharing conditions.

The main argument of the present study is that dual-task practice with varying priorities may lead to the development of different internal models compared with practice under fixed levels of priorities. These differences are predicted to affect the efficiency of time-sharing performance.

Experimental overview and predictions

Two experiments were conducted to compare spontaneous and instructed acquisition of attention control under time-sharing conditions.

Acquisition processes and transfer of training were investigated in both experiments. Three groups of subjects in the first experiment and two in the second experiment were trained in the performance of two tasks, first separately (session I) and then together. In the first experiment, one group was trained in the performance of two tasks under different combinations of task priorities (variable priorities group - VP). This group was presented with real time feedback on performance and display of demand

levels. A second group of subjects practiced the concurrent performance of the same pair of tasks without this display or feedback bargraphs and with no real-time manipulation of task priorities (No bargraphs group - NB). A third group practiced with feedback bargraphs only under equal priority conditions, with no changes in task emphasis (Equal Priority group - EP). In the second experiment only two experimental groups VP and EP were contrasted.

In both experiments, subjects were transferred to a new condition in which priority instructions and feedback displays were eliminated, several joint performance combinations of task difficulty were presented and subjects were instructed to maintain constant levels of performance. In addition, subjects in both experiments were transferred to a dual task situation in which one of the tasks was new.

Selection of Experimental Tasks

Selection of proper task combinations is crucial in the study of the effects of different training strategies on the voluntary control of resources. Experimental tasks have to meet two main requirements:

a) Tasks should compete for a common resource, otherwise there is no point in investigating resource allocation strategy (Gopher and Navon 1980).

b) Tasks should be difficult enough to assure scarcity of available resources, but not too difficult to avoid restriction of range due to data limitation (Norman and Bobrow 1975).

Several proponents of stages in information processing have argued that the stage of response selection is the most limiting and resource-consuming in the processing chain (Trumbo and Noble 1970; Deutch and Deutch 1963; Kerr 1973; Welford 1968, 1978; Shiffrin and Schneider 1977; Duncan

1980). In order to ensure competition for common resources, two tasks that seem to draw heavily on response selection were selected for the first experiment. One task was a dual axis pursuit tracking task, the difficulty of which was varied by manipulating the second order acceleration components of the controlled element dynamics. Gopher and Navon (1980) showed that tracking tasks are primarily loaded on the response side. A second task selected . was a code entry letter typing task. In the second experiment the same letter typing task was performed together with a digit classification task.

Pilot Study

A pilot study was conducted to evaluate the experimental tasks, the selection of difficulty parameters and general experimental procedure (Gopher, Brickner and Navon, in press). Six subjects performed the tracking and letter typing tasks in single and dual task conditions with two types of letter typing difficulty manipulations and three levels of intertask priorities.

The following is a summary of those results pertinent to the current experiments:

a) Significant interference between tracking accuracy and letter typing performance was found in all dual task combinations with all difficulty manipulations and priority changes. These findings indicate the existence of competition for a common resource.

b) Both tasks were highly sensitive to manipulation of task priorities.

c) Difficulty and priorities interacted in their effects on joint performance, thus showing that the selected manipulation of letter typing difficulty taps a resource shared by both tasks.

d) The addition of feedback indicators and moving bargraphs did not interfere with performance on the experimental tasks. After a brief initial period of training, there was no significant difference between performance of the tasks with and without feedback indicators at equal priority levels.

These results satisfy the initial requirements for selection of tasks for the present study.

Research hypotheses

Effects of differential training strategies on the ability to control resource allocation in concurrent performance have not been studied before. Thus, it is difficult to generate predictions or specific hypotheses. We end this introduction section by listing several research questions rather than proposing formal hypotheses:

1) Effects of practice with priority changes on dual-task performance: What would be the effects of differential practice methods on the performance levels of each of jointly performed tasks? Based on previous arguments on the development of automaticity with training (Schneider and Shiffrin 1977; Shiffrin and Schneider 1977; Logan 1979), it is expected that the equal priority group (EP) and the no bargraphs group (NB) will do better than the variable priority group (VP) with extended practice, because consistent training conditions (no change of priorities) may enhance the development of automaticity. It is also possible that prolonged consistent training will yield some degree of integration between tasks, thus reducing their joint resource demands (Neisser 1976).

The differences between the EP and NB groups depend on the contribution of real time feedback to the specific task involved. When the task itself lacks clear feedback cues on the quality of performance, the EP

group is expected to perform better.

2) Transfer to a changing difficulty condition with fixed performance levels: The VP group is hypothesized to be better than the EP and NB groups on these conditions which demand flexibility in resource allocation in order to maintain constant levels of performance. The VP group is given the opportunity to develop a more comprehensive and more sensitive internal model that would enable it to mobilize resources to protect performance. Along the same line of arguments, development of automatization or integration in the EP and NB groups may impair their ability to react flexibly.

3) Generalization to a new task configuration: What portion of the skill is generalizable when a new task configuration is introduced? It is clear that a new configuration requires establishment of a new internal model. It is unclear how much of the old attention skills can be transferred to the new situation. We can only speculate that if the VP group acquired appreciation and knowledge on the flexibility of resource allocation strategies, this knowledge would be to its advantage in the acquisition of a new model, compared with the EP and NB groups which were subjected to a rigid schedule of training.

EXPERIMENT I

METHOD

Experimental Tasks

Tracking: A dual axis pursuit tracking task served as one experimental task. Subjects were seated at a distance of approximately 70 cm from a CRT screen (22 x 22 cm about 18 degrees visual angle) on which a square and an X figures (1.5 x 1.5 cm) were displayed (Figure 2). The square served as a target symbol and moved continuously along the two dimensions of the screen, driven by a band limited, random, forcing function with a cutoff frequency of .7Hz, controlled by a second order digital filter. The X symbol was controlled through a single, two-dimensional spring-loaded, hand controller. Right and left deflections of the hand controller moved the X on the screen in the horizontal axis, while fore and aft deflections were translated into up and down movement on the screen respectively. Hand controller deflections did not affect the position of the X on the screen directly, but changed the acceleration component of its movement. Control dynamics generally followed the equation

$$(1)\quad \theta = (1 - \alpha)\ 0.75\ (\text{velocity}) + (\alpha)\ 0.3\ (\text{acceleration})$$

Theta represents control system output. Alpha values in equation (1) were manipulated to vary the relative contribution of velocity and acceleration components to system response.

The tracking system was installed on the right hand side of the subjects' chair and operated by the right hand.

Insert Figure 2 about here

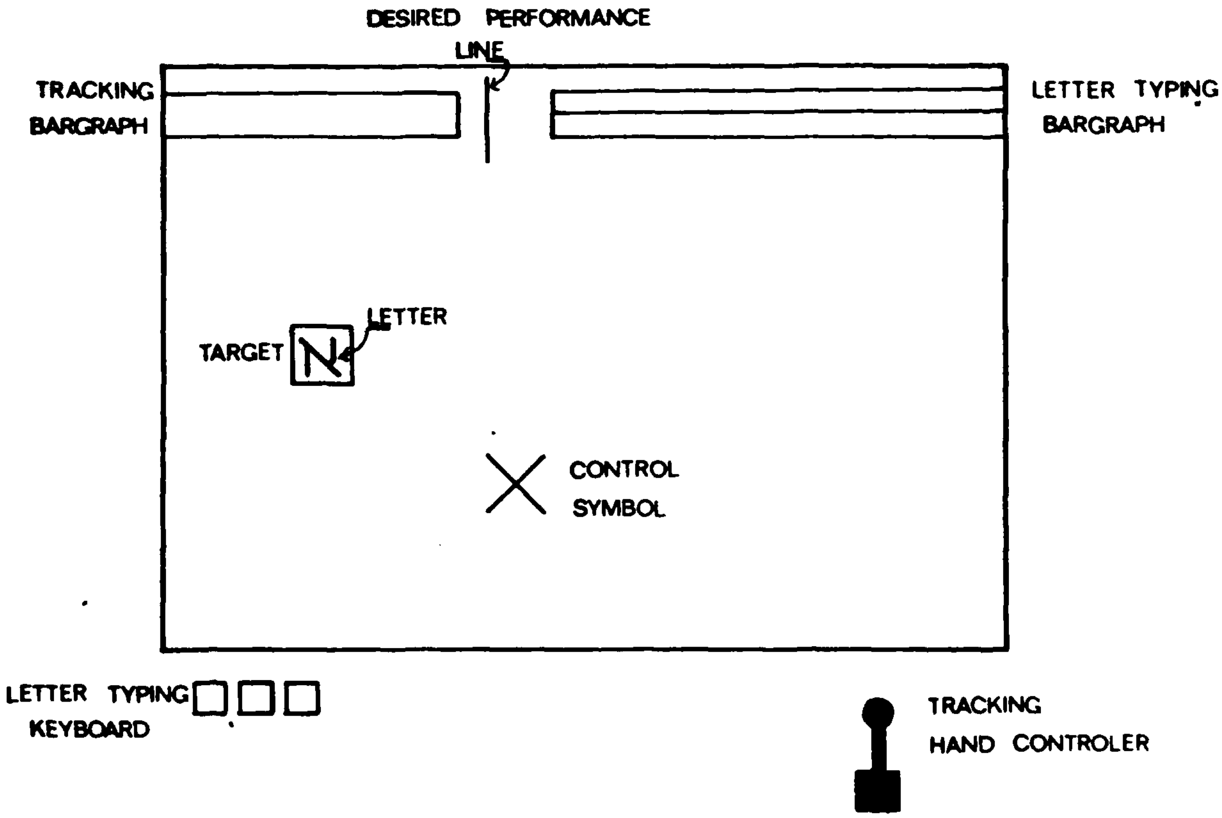


Fig. 2: Subjects display in concurrent performance of Tracking and Letter-Typing

<u>Letter typing task</u>: The letter typing task was based on a 3 key letter-shape typewriter for the Hebrew language, developed by Gopher and Eilam (1979). In the Letter-Shape keyboard every letter of the Hebrew alphabet is entered by two successive chords, each comprised of some combination of the three keys.

Letter codes can be best envisioned within a six cell imaginary matrix in which three columns represent the three keys and two rows the two successive chords (Appendix A). The codes were designed to resemble as much as possible the graphic form of the letters in printed Hebrew. For this purpose, each of the cells in the imaginary matrix was treated as a graphic element. Letter forms were created similar to the way that symbols in graphic displays are constructed from dots and strokes. Some examples of different letter codes are presented in Appendix A.

The letter typing task was configurated as a self-paced reaction time task. Single letters were displayed inside the target square of the tracking task (see Figure 2). This was done in order to avoid as much as possible interference due to peripheral vision. Subjects had to cancel letters by typing the code of the displayed letter. If the correct code was entered, the letter disappeared and after an interval of 100 msec another, randomly selected letter, was displayed. If incorrect codes were repeatedly entered or subjects failed to respond within a time interval of 3 seconds, the displayed letter was automatically changed by the computer.

In a different version of the code typing task, the subject could write each letter on the screen by typing the proper code. This version was used for initial training on the task.

Three groups of 4 letters selected empirically from the set of 22 Hebrew letters were used in the experiment. The first group was composed of 4 easy letters, in which the two successive chords of each letter code were identical (Appendix A). A second group included 4 difficult letters, letters in which chords were different and asymmetrical (Appendix A). Finally, a group of 4 medium-difficult letters was selected (Appendix A).

Difficulty of letter codes was determined empirically from the results of an initial reaction time test. It appears to stem from motor factors related to finger combinations and transition from first to second chords (see Gopher, Brickner and Navon, in press). The three letter sets could be presented separately to manipulate task difficulty or mixed to create equal difficulty sets.

<u>Digit classification task</u>: During the fifth experimental session, subjects were required to perform the tracking or letter typing task with a digit classification task. In this task, a single digit presented on the screen had to be classified into one of two predefined groups by pressing a key on a two button keyboard. Digits were presented for 300 msec, followed by a 1200 msec interval in which masking square appeared in the digit's location to minimize effects of iconic storage. Sets of digits were changed between two minute trials to avoid consistent mapping. Difficulty on this task was manipulated by changing the numberof digits in each group.

When the digit classification task was performed concurrently with tracking, digits were displayed within the target square, and the keyboard was mounted on the left hand side. When digit classification was performed with the letter typing task, the digit was presented in a fixed location to

the right of the displayed letter and responded to by the right hand. Classification performance was evaluated by a combined speed-accuracy score computed from the following equation:

$$(2) \quad WRT = \frac{NC \times CRT + (NF+MISS) \times 1500 \text{ msec}}{NT}$$

where: WRT - Average weighted reaction time score

NC - Number of correct reactions

CRT - Average correct reaction time

NF - Number of false reactions

MISS- Number of misses

NT - Total number of stimuli presented (+NC + NF + MISS)

Note that 1500 msec is the interstimulus interval, thus this equation strongly discourages guessing and emphasizes accurate classification.

Priority manipulation by feedback indicators: Subjects could be presented with an on-line continuous feedback on their performance. Feedback indicators comprised a short, static vertical line and two moving horizontal bar-graphs (see Figure 2). The static line represented the desired level of performance in terms of tracking error and correct response time to letters. Desired performance was determined in reference to a normalized baseline distribution of performance obtained for each subject at the end of the second training session. Subjects were generally required to perform the tasks in the dual-task condition at their average level in single-task performance. The difference between the moving bar-graph of each task and the desired performance line reflected the momentary difference between actual and desired performance. This difference was computed continuously by subtracting the momentary error score (for tracking) and reaction time score (for letter typing) from the desired score and dividing

the outcome by the standard deviation of the baseline distribution. The right side bar-graph represented performance on the letter typing task and the left side bar-graph represented tracking performance.

Task priorities could be manipulated by moving the desired performance line from the center (equal priorities) to the left side (high priority for letter typing and low priority for tracking) or to the right side (high priority for tracking and low for letter typing). A priority level of, say, .75 for tracking corresponded to a level of performance that assumed the 75th percentile in the baseline distribution of tracking performance for that subject. That is, an instruction to put priority of .75 was actually a requirement to perform at a level better than the lowest 75 percent of the baseline performance levels.

The use of a single vertical desired performance line with horizontal bar-graphs in this experiment is a change from the display used by Gopher and North (1977) and Gopher and Navon (1980). The present display has several advantages over the old procedure, since it reduces the use of peripheral vision and enhances the ability of subjects to compre directly the relative differences of the two bar-graphs from desired performance.

Verbal Feedback and Monetary Rewards

In order to motivate subjects and encourage them to maintain the required allocation of effort, verbal feedback and monetary reward were used during experimental sessions 2 - 5. In the beginning of each trial subjects were told the expected level of performance for that trial. At the end of the trial they were informed on their actual level of performance. In addition, monetary rewards were given in each trial. At the end of each trial mean distance between actual and desired performance was computed for each task and the reward was inversely proportional to the larger difference between actual and desired performance on the two tasks. If the subject reached the demand levels on both tasks, he

received 10 Israeli pounds (about .3 US$) for that trial. A distance of two standard deviations from desired performance on one task resulted in zero reward. The unique property of this reward procedure was that it discouraged subjects from allocating all their resources to one task and neglecting performance on the other task. If performance exceeded the desired performance level on both tasks, the reward was proportionally higher than 10 IL.

Experimental groups

Subjects were assigned into one of three experimental groups:

1) Variable priority group (VP): Subjects in this group practiced dual-task performance with five different priority levels. The five priority conditions employed were: .25, .35, .5 (equal priority), .65, .75.

2) No bargraphs group (NB): Subjects in this group performed both tasks with no real time feedback indicators or priority demands. They were instructed verbally to consider both tasks equally important, and were demanded to reach a pre-set performance level on each task.

3) Equal priority group (EP): In this group subjects practiced dual-task performance with real time priority and feedback indicators. However, only equal priority conditions (.50 - .50) were employed during the whole period of practice.

Procedure

All subjects participated in five, two-hours experimental sessions. No two sessions were held on the same day.

Session I - Single task training: The first session was devoted to initial familiarization and training on each task by itself. Subjects were presented with the letter typing task and practiced until they could type all letters twice without error. Training proceeded by 12 two-minute trials using the set of all 22 Hebrew letters, followed by nine trials in which each of the three equally difficult subsets of 4 letters was presented three times. In addition, 12 three minute trials of adaptive tracking were interweaved in the letter typing trials. Adaptive techniques were employed to increment tracking difficulty by gradually increasing the proportion of acceleration determinants in the control dynamics of the hand controller. Acceleration percentage was incremented whenever tracking errors were lower than the specified criteria of performance. Performance criteria in the adaptive equation were ten percent of scale root mean square errors (RMS) on each axis and adaptive steps were .0005 for every 60 msec. computer decision cycle.

At the end of this session each subject was assigned to one of three experimental groups: the variable priority (VP), no bargraphs (NB), or equal priority (EP) group. Subjects in the three experimental groups were matched according to their performance scores on both experimental tasks.

Session II: The second experimental session started with five trials of initial dual-task training, followed by ten trials of dual-task training according to the training conditions of each experimental group. In addition, 3 trials of letter typing alone and two trials of tracking alone were performed to evaluate single task changes and obtain the baseline performance levels for the manipulation of task priorities during the next session.

Session III: Session III consisted of 25 trials of dual-task training under the different training conditions.

Session IV: In the fourth session all three groups were transferred to a dual-task changing difficulty condition with a requirement to maintain fixed levels of performance. On-line feedback indicators and priority manipulations were eliminated. Instead, commensurate manipulations of tracking and typing difficulty were performed. The set of four easy letters was combined with a difficult tracking task: the four medium difficult letters with medium difficulty tracking; and the four difficult letters with an easy tracking task. Tracking difficulty was manipulated by setting the acceleration level 20% higher (difficult tracking) or lower (easy tracking) than the value employed for each subject in the third session (recall that this value was obtained in initial adaptation). In all three difficulty combinations, subjects were required to maintain a constant performance level. They received verbal instruction on the expected level of performance and monetary rewards according to their achievements. Each difficulty combination was presented four times, leading to a total of 12 three-minute trials. In addition, one single task tracking trial and three single letter typing trials (one for each letter set) were presented to evaluate single task performance.

Session V: In the final session all subjects were transferred to a new task configuration in which tracking or letter typing were paired with the digit classification task. Half of the subjects in each group performed typing and digit classification, while the other half performed tracking and classification. The procedure was similar to that of session IV. A difficult digit classification task was combined with easy tracking, or easy letter set. A medium difficult digit classification task with medium difficult tracking or typing, and easy classification

with difficult tracking or letter typing. Classification difficulty was manipulated by using 2, 4 or 8 digits sets. Dual-task trials were preceded by six single task familiarization trials of medium difficulty digit classification task. Then, 15 dual-task trials were performed. Again, three single digit classification trials - one for each level of difficulty - were administered to evaluate single task performance. Verbal instruction and monetary rewards were given as in Session IV.

Subjects

Eighteen male, right-handed subjects, ranging from 19-25 years of age, participated in the experiment (six in each experimental group). Subjects were paid hourly rates for the first session and earned monetary rewards for their performance in sessions II - V.

RESULTS

Initial training

Letter typing: Average response times for letters in the last six trials of letter typing in session I are presented in Table I. In each of the six averaged trials, one of the three, equal difficulty, 4 letter sets was presented. Letters were displayed within the moving square of the tracking target, but the tracking task was not performed.

Differences between groups are small and reflect the matching of subjects assigned to the three experimental groups.

Table I. Response times and Standard Deviations (msec) for letter typing at the end of the first experimental session.

	Experimental group VP (N=6)	NB (N=6)	EP (N=6)
Letter $\bar{X}$	1395	1404	1383
Typing SD	166	201	175

Tracking performance: During the first experimental session, subjects performed 10 tracking trials in which acceleration percentage was adapted. Final levels of acceleration percentage (α level in equation 1) reached by the subjects in the three experimental groups, are presented in Table II.

Table II. Average final levels of acceleration reached at the end of the first experimental session.

			Experimental Group VP (N=6)	NB (N=6)	EP (N=6)
Tracking axes	X	$\bar{X}$	.623	.628	.597
		SD	.133	.164	.140
	Y	$\bar{X}$	.491	.410	.500
		SD	.194	.203	.201

The lower levels of acceleration reached on the vertical axis reflect the greater difficulty of tracking on this dimension and are consistent with earlier findings (Gopher and Navon 1980; Gopher, Brickner and Navon, in

press). Nevertheless, on both axes the proportional contribution of the acceleration component was large enough to create relatively difficult control dynamics.

It should be noted that due to the high intersubject variability in the acceleration variable, relative to letter typing performance, matching of subjects in this variable was somewhat more difficult. Exact matching on this task was, however, of lesser importance, because each subject performed tracking at his own adapted control dynamics.

At the end of the adaptive phase, control dynamics was fixed and tracking performance was measured by the two-dimensional root mean square (RMS) vector differences between target (t) and control (c) screen position ($\sqrt{(X_t - X_c)^2 + (Y_t - Y_c)}$). Tracking error scores were expressed as percent of maximum screen separation between target and controller.

Initial levels of dual-task performance

All experimental groups performed at the beginning of the second experimental session five dual-task trials without feedback indicators. Table III summarizes the results of these trials. These results substantiate the claim that the three experimental groups were properly matched not only on single task performance but also in initial dual-task capabilities.

Table III. Average response times for letters (msec) and RMS tracking errors (percent of scale) in 5 initial trials of dual-task training.

		Experimental Group		
		VP	NB	EP
Letter typing	$\bar{X}$	1581	1601	1598
	SD	344	316	212
Tracking	$\bar{X}$	.384	.369	.395
	SD	.55	.51	.66

The effects of priority manipulation on performance

To evaluate the effects of the priority manipulation on performance in the VP group, a two-way analysis of variance (priority x replications) was performed on the last twenty practice trials. Priority effects were large and significant on both tasks: tracking performance $F(4,20) = 29.30$ ($P < 0.001$), letter typing $F(4,20) = 12.59$ ($P < 0.001$). An important finding in this analysis was that practice effects (trials) did not interact with priorities on either task.

Figure 3 depicts the effects of priorities on performance in the two tasks.

Insert Figure 3 about here

It can be seen that on both tasks the effects are nearly linear. There is a strong tradeoff between the two tasks throughout the scale of priorities. These tradeoffs are better clarified in Figure 4, in which the performance operating characteristics (POC) of the joint performance

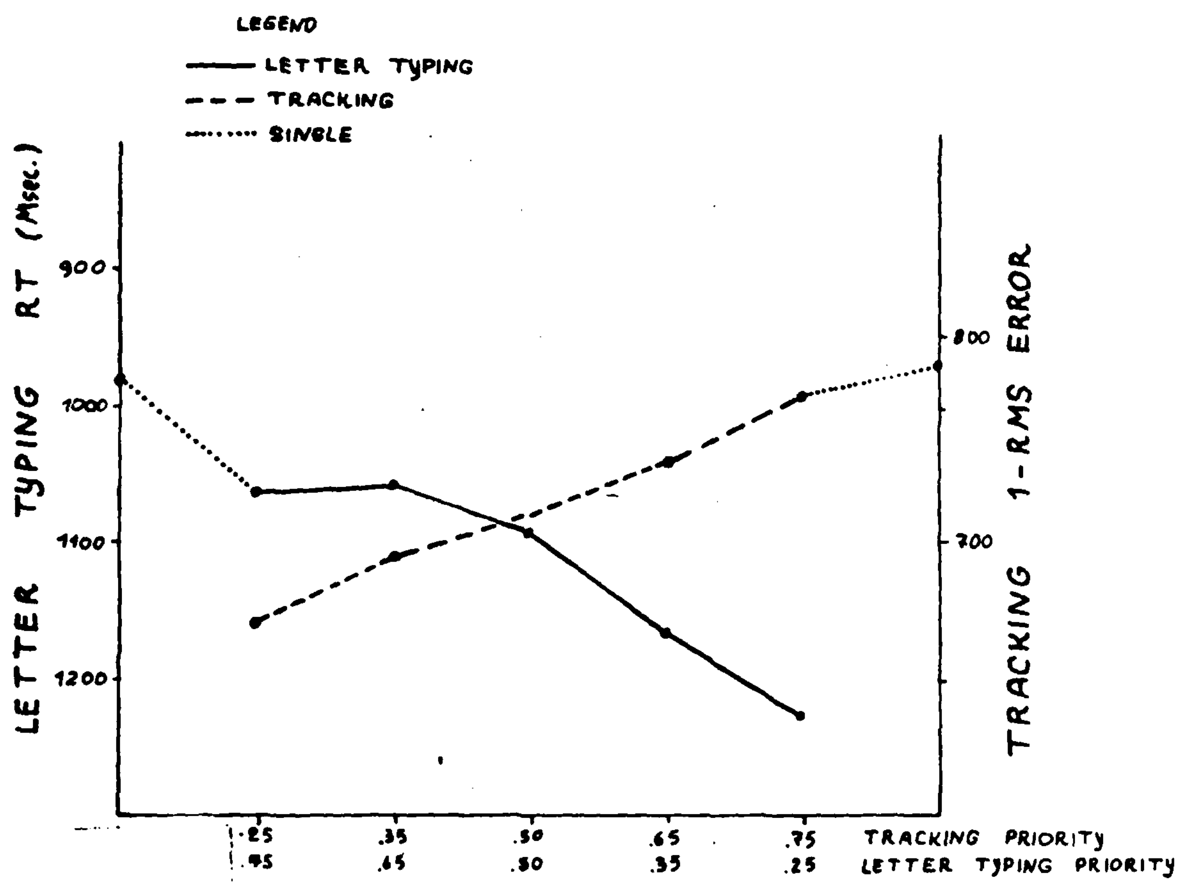


Fig. 3: The effects of priority changes on Tracking and Letter-Typing performance of the VP group (N-6)

of tracking and letter typing are presented.

Insert Figure 4 about here

Differential training under time-sharing conditions

Figure 5a, b presents the training effects on letter typing and tracking performance in the second and third experimental sessions. Each point in these curves represents average performance in one trial in which the three experimental groups (including the variable priorities group) performed both tasks with equal priorities. Seven equal priorities trials were given during training of the variable priorities group, and those are compared with performance levels of the EP and NP group at the same time point.

Insert Figure 5a, b about here

On both tasks a large difference between the performance levels of the three groups developed with training. Gradients of learning in the variable priority group (VP) were much steeper than those of the equal priority (EP) and no bargraph (NB) groups, leading to an increasing difference in the overall quality of performance in favor of the VP group. A two-way analysis of variance (experimental group x training) was performed on each task to test the significance of these differences. For tracking performance, both group effect ($F(2,10) = 16.48$; $P < 0.001$) and training (trials) effect ($F(6,30) = 7.90$; $P < 0.001$) were statistically significant. The interaction between groups and training reached only the .10 level of significance ($F(12,60) = 1.85$; $0.05 \quad P < 0.10$). For letter typing, the training effect was highly significant ($F(6,30) = 11.42$; $P < 0.001$). Group effects, although apparent in Figure 3, reached only .10 level of significance ($F(2,10) = 3.95$; $P < 0.10$).

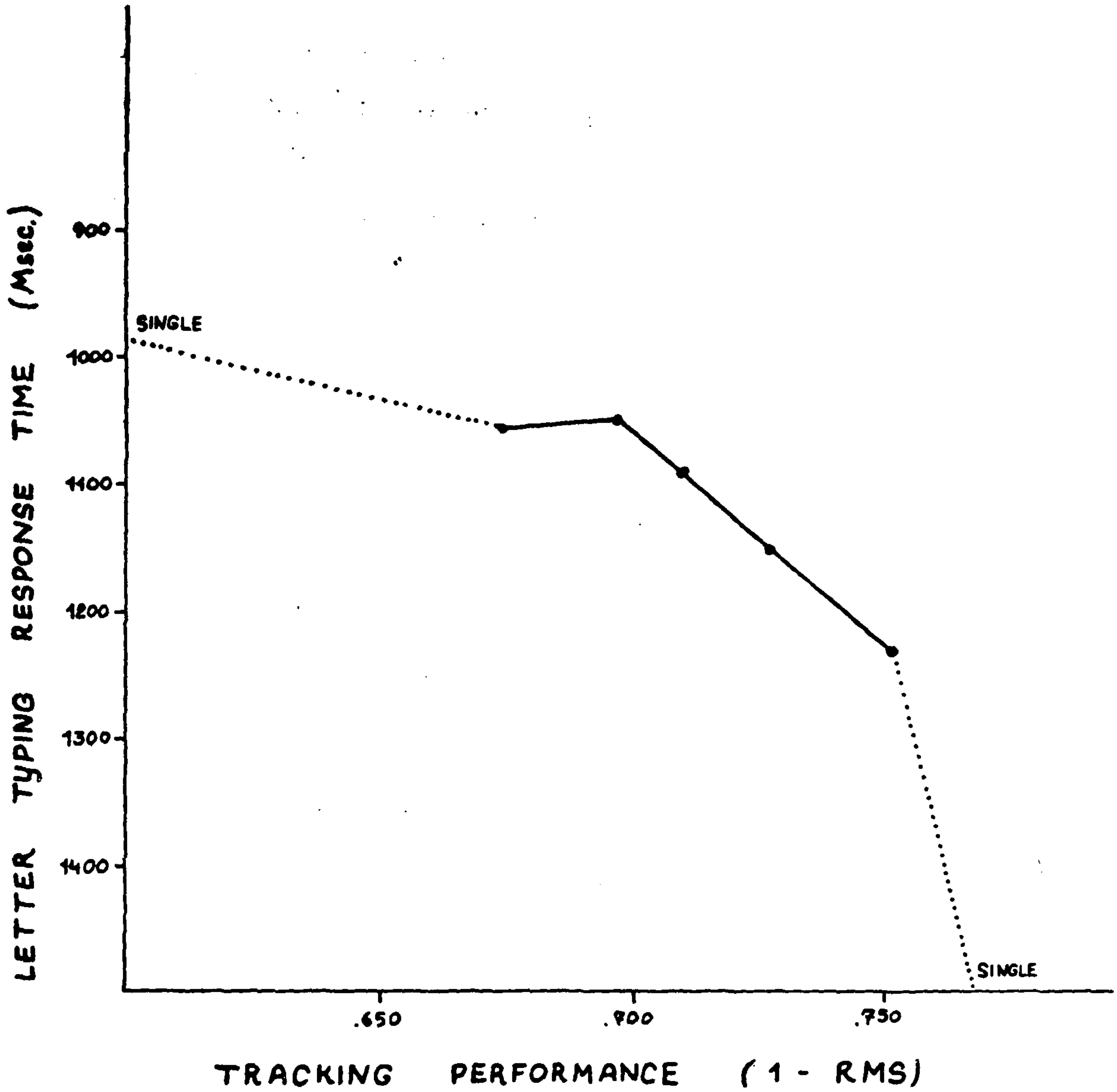


Fig. 4: POC depicting the tradeoff between Tracking and Typing performance as a result of priority changes

The differences between the three experimental groups were further explored by comparing their performance on the last 20 trials of the third experimental session. Recall that the VP subjects performed five different priority combinations while EP and NB subjects performed all trials under equal priorities instructions. The results of this comparison are presented in Table IV.

Table IV. Mean dual-task performance of letter typing (msec) and tracking (RMS error) on the last twenty differential training trials.

		Experimental group		
		VP	NB	EP
Letter typing	$\bar{X}$	1120	1219	1234
	SD	180	231	205
Tracking	$\bar{X}$	.289	.359	.324
	SD	.44	.73	.61

A two-way analysis of variance (group x training) was performed on the performance scores of each task. For tracking, both main effects were statistically significant: group effects ($F(2,10) = 12.54$; $P < 0.001$), training effects ($F(3,15) = 4.86$; $P < 0.05$). For letter typing again the group effect reached only the .10 percent level of statistical significance ($F(2,10) = 3.11$; $P < .10$), while training effect was significant ($F(3,45) = 6.46$; $P < 0.01$).

Paired comparisons that were conducted for tracking performance to test the differences between the EP and NB groups (Fig. 5b), showed that the differences were not significant ($F(2,120) = 1.96$).

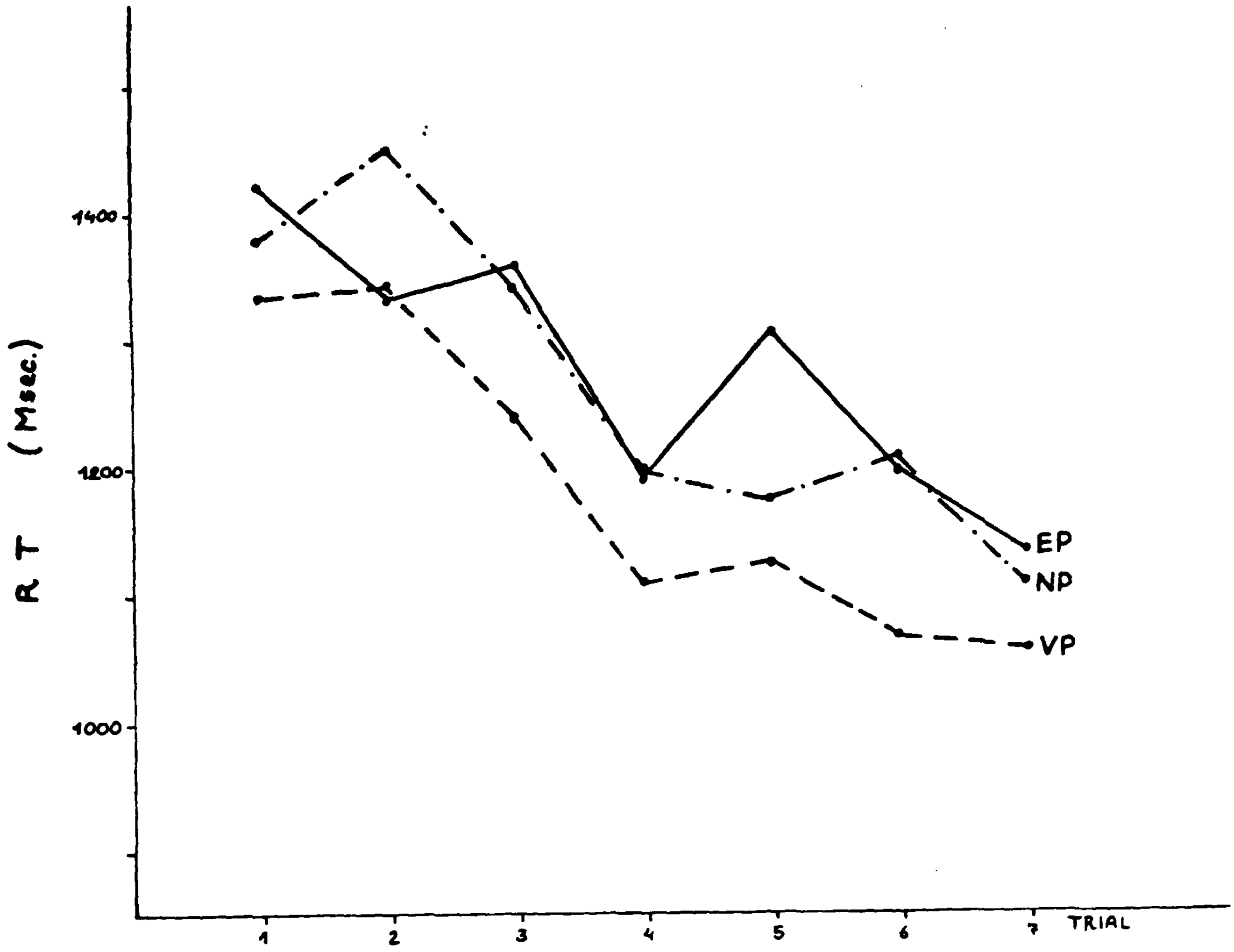


Fig. 5a: Letter-Typing performance (Msec) during 7 equal priority trials, for each of the three experimental groups.

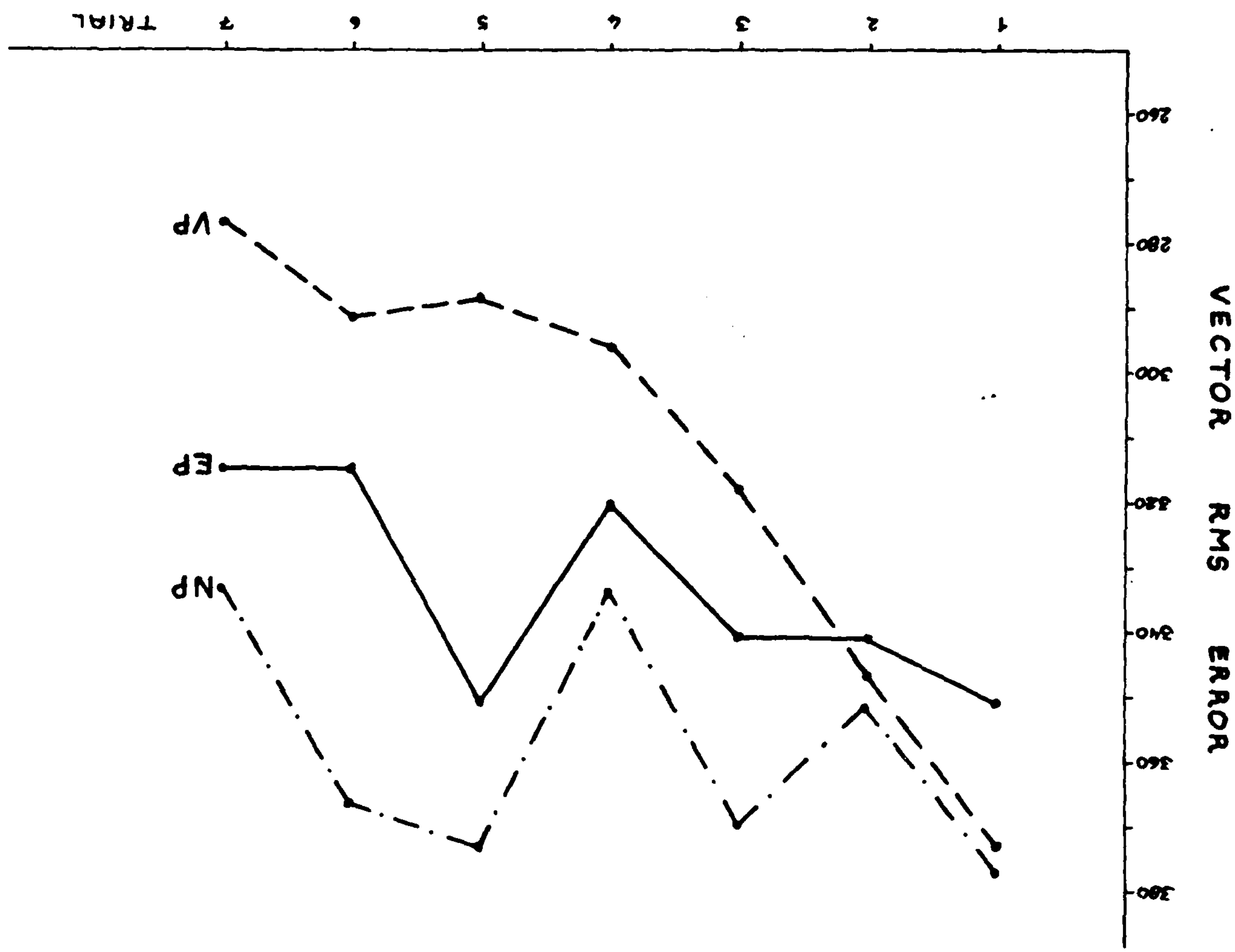


Fig. 5b: Tracking RMS error scores during 7 equal priority trials for each of the three experimental groups.

It is interesting to note that on both tasks average performance of the EP and NB groups was close to the performance of the VP group at the lowest priority level.

<u>Transfer to changing difficulty conditions with fixed performance levels</u>

To recall, in the fourth experimental session, the three groups were transferred to a new condition in which on-line feedback was eliminated and subjects were instructed to maintain constant levels of performance in spite of commensurate changes in task difficulty.

Figure 6a, b presents the results of letter typing and tracking performance in four successive replications of difficulty manipulation. Performance on both tasks revealed clear effects of group affiliation, task difficulty and a strong interaction between the two. The general pattern on both tasks was remarkably similar. Average performance levels of the VP group were much better than those revealed by the other two groups. In addition, performance of the EP and NB groups was strongly affected by the difficulty manipulation, while the VP group had smaller slopes indicating their ability to protect performance in view of difficulty changes.

Insert Figure 6a, b about here

A three-way analysis of variance (group x difficulty x training) was conducted for each task. For letter typing, all main effects reached statistical significance. Experimental group effect ($F(2,10) = 9.28$; $P < 0.01$); difficulty effect($F(2,10) = 46.28$; $P < 0.001$) and training effect ($F(3,15) = 5.40$; $P < 0.05$). The interaction between group and difficulty was also significant ($F(4,20) = 4.87$; $P < 0.01$).

All main effects and group-by-difficulty interaction were also

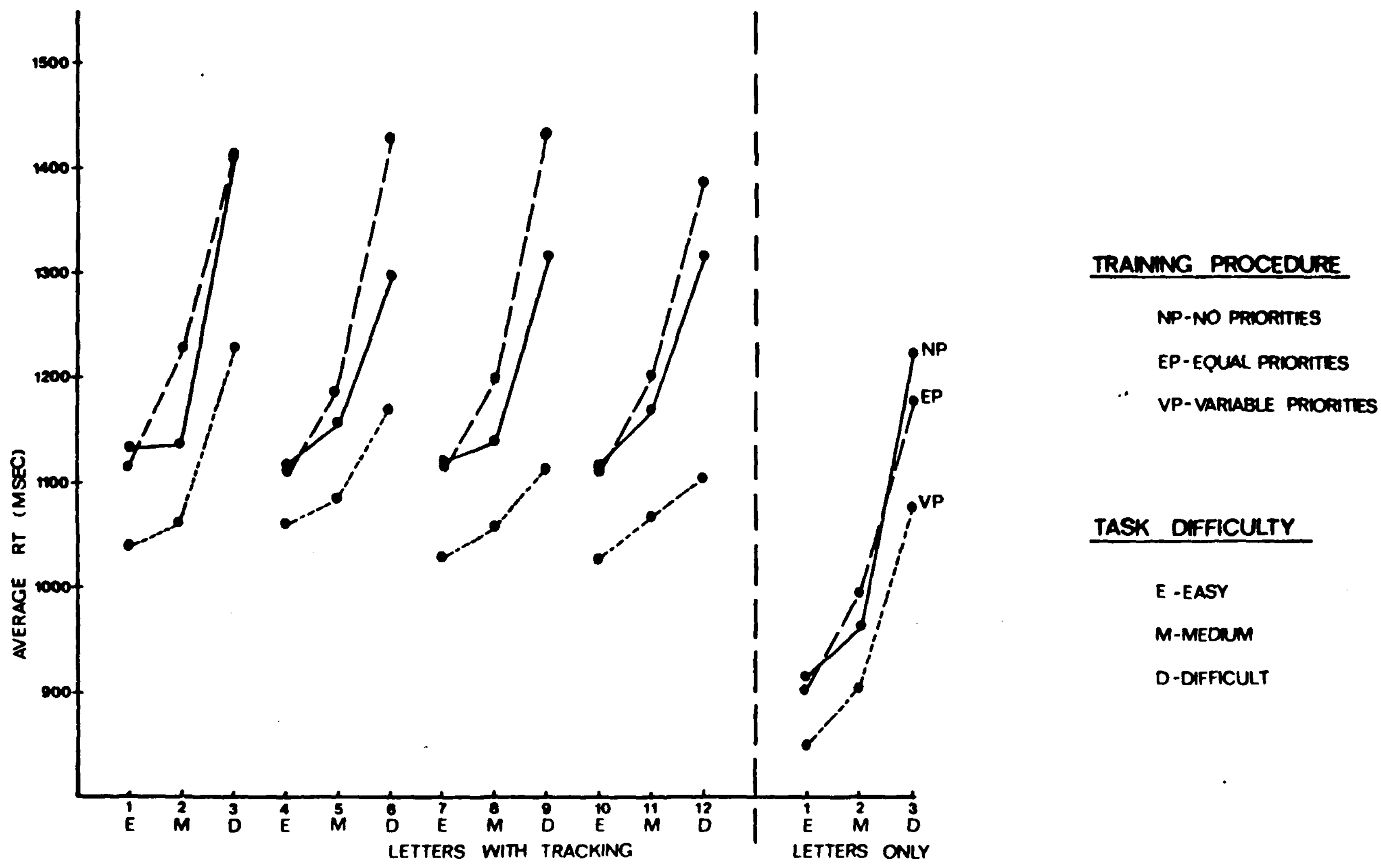


Fig. 6a: Letter typing performance with tracking under changing difficulty conditions. Also plotted are performance levels in single task conditions (N=18).

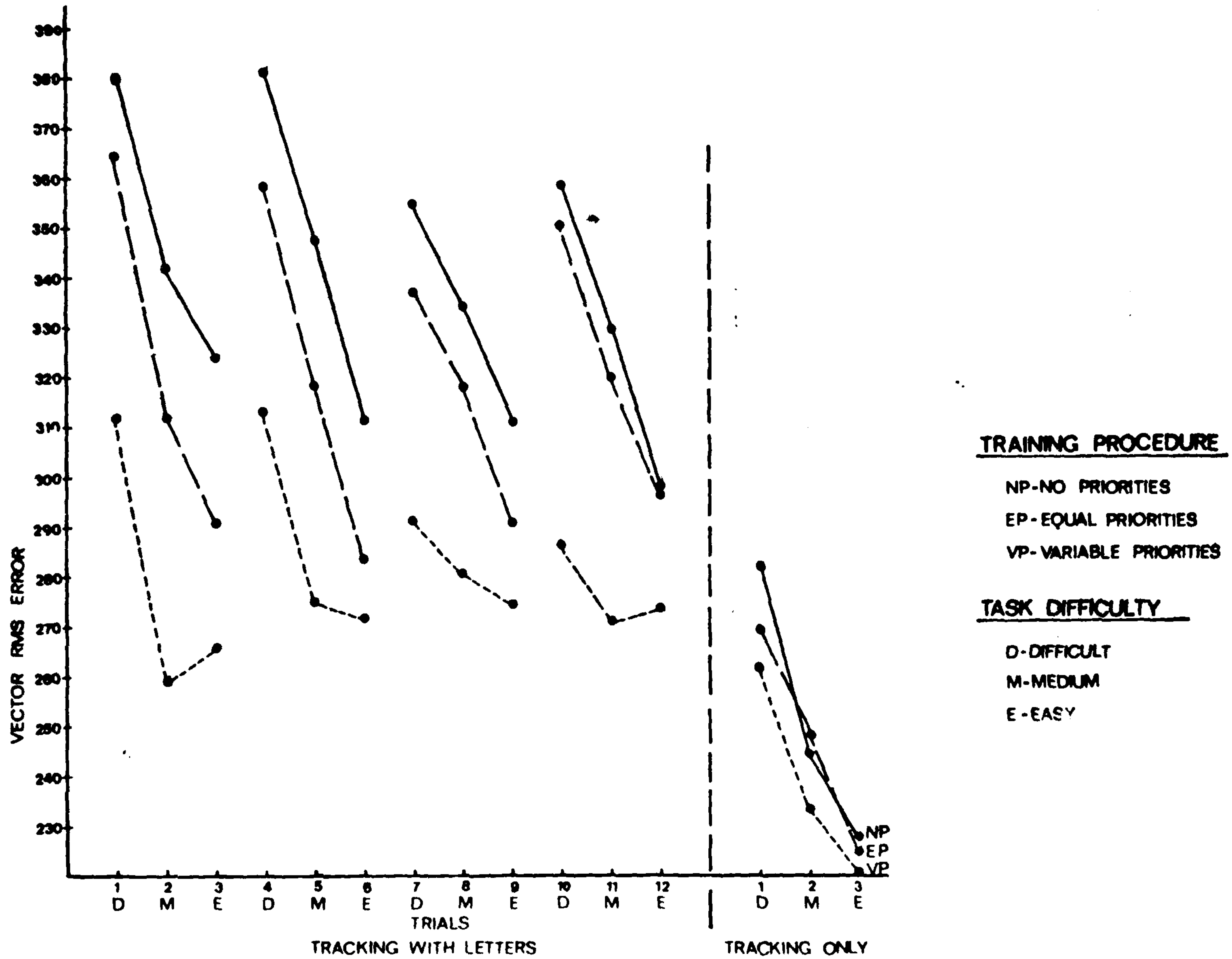


Fig. 6b: Tracking performance with letter typing under changing conditions. Also plotted are performance levels in single task conditions (N=18).

significant for tracking performance. Experimental group effect ($F(2,10) = 14.00$; $P < 0.001$); difficulty effect ($F(2,10) = 32.24$; $P < 0.001$), and training ($F(3,15) = 3.71$; $P < 0.05$). The interaction between group and difficulty was also significant ($F(4,20) = 3.34$; $P < 0.05$).

A Schaffe paired comparison test on tracking performance revealed significant group differences between the EP and NB group ($F(2,12) = 7.40$; $P < 0.01$) between VP and EP groups ($F(2,120) = 3.29$; $P < 0.05$) and of course, between the VP and NB groups ($F(2,120) = 11.03$; $P < 0.001$).

Note that for both tasks and for all three experimental groups single task performance was much better than dual task performance. In addition, the differences between the three experimental groups almost disappeared and all three exhibited steep slopes with difficulty changes. These findings indicate that the relatively flat slopes of the VP group in the dual task performance were indeed an outcome of an improved time-sharing capability and not a ceiling effect or a mere result of improved performance ability on each task.

Letter typing and tracking combined with a digit classification task

In the fifth experimental session, half of the subjects in each experimental group performed tracking concurrently with a digit classification task, the other half performed letter typing with digit classification. Experimental conditions replicated the changing difficulty design employed in the fourth session.

Tracking and digit classification: The results of tracking performance with digit classification are presented in Figure 7a, b. In all three experimental groups and for both tasks, difficulty changes resulted in steep changes in performance levels. Subjects in the VP group seem to

---

Insert Figure 7a, b about here

---

be better on the average in their tracking performance (see Fig. 7a) but they also could not protect performance.

A three-way analysis of variance (group x difficulty x training) was conducted to evaluate these results. A significant group effect was revealed on the tracking task $F(2,4) = 8.81$ ($P < 0.05$). The difficulty effect was also significant $F(2,4) = 14.95$ ($P < 0.05$). On digit classification there were no significant group differences ($F(2,4) = 1.07$). The difficulty effect was very large $F(2,4) = 110.76$ ($P < 0.001$) and there was a significant training effect $F(4,8) = 7.02$ ($P < 0.01$). This result is not surprising because the task was new to the subjects. No interaction on either task approached statistical significance.

Letter typing and digit classification: Concurrent performance of these two tasks created an entirely new situation for the subjects because it involved two discrete tasks, one of which was self-paced (letter typing) and the other externally paced (digit classification). Thus, a new coordination strategy had to be developed. Performance on the two tasks is depicted in Figure 8a, b.

Insert Figure 8a, b about here

It can be seen that performance on both tasks was severely impaired as compared to the performance of these tasks with tracking. Furthermore, the strong interference between the tasks caused nonmonotonic effects of the difficulty manipulation on performance. In most of the trials, performance on the easy task version was worse than performance on the medium difficulty version. These effects can probably be attributed to the interference from the concurrently performed task, which was simultaneously

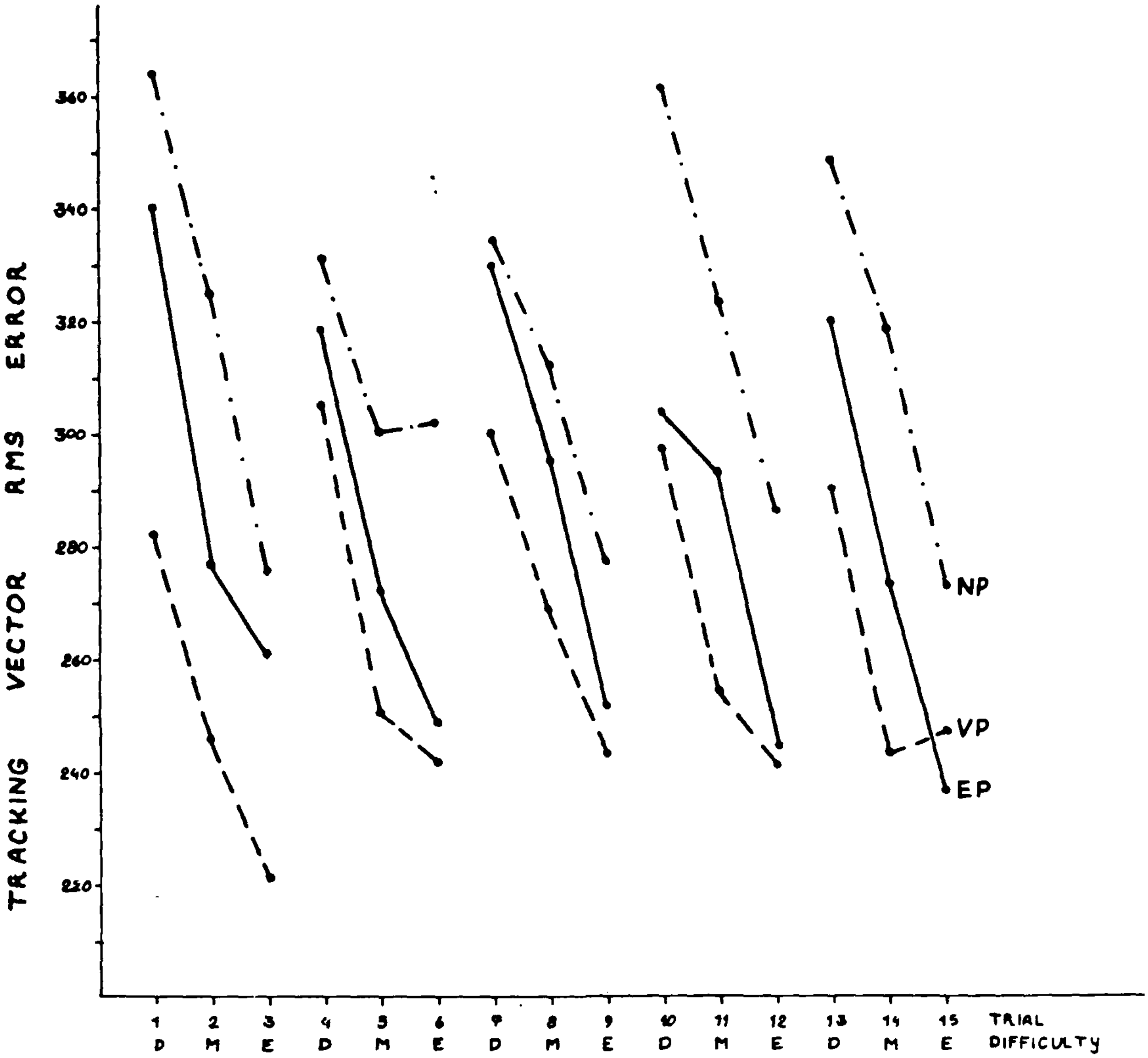


Fig. 7a: The effect of difficulty manipulation on tracking performance (a) under time-sharing conditions with digit classification.

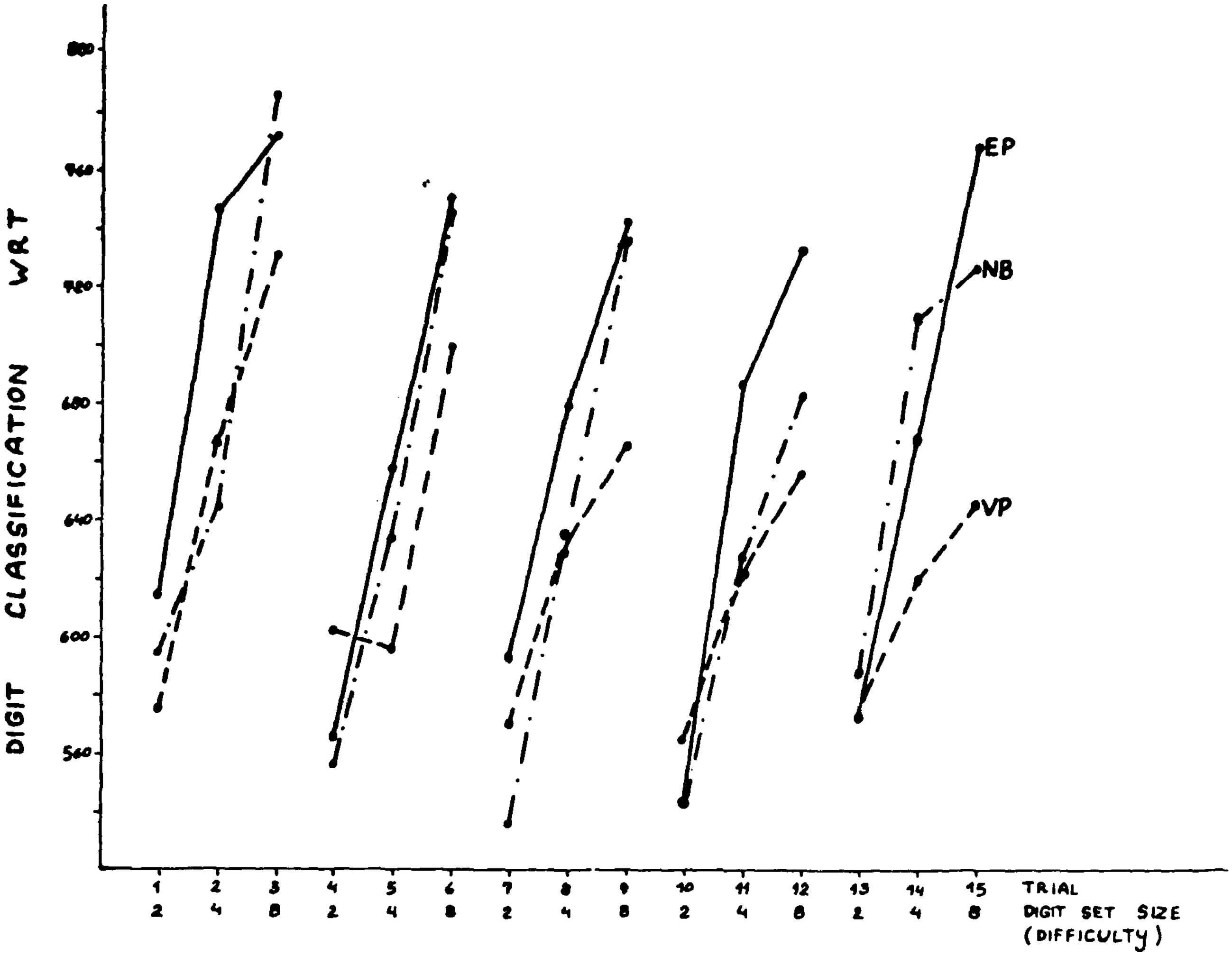


Fig. 7b: The effects of difficulty manipulation on digit classification performance under time-sharing conditions with tracking.

presented at its most difficult version. In the medium difficulty conditions, both tasks were medium.

A three-way analysis of variance revealed significant difficulty effects on both tasks - letter typing $F(2,4) = 9.31$ ($P < 0.05$) and digit classification $F(2,4) = 29.84$ ($P < 0.001$). Training effects in digit classification were also significant - $F(4,8) = 8.93$ ($P < 0.01$). Neither group effects nor any interaction were significant.

Comparison of digit classification in concurrent performance with tracking and with letter typing: Digit classification was performed much better when combined with tracking than with letter typing. The weighted reaction time score for digit classification with tracking was 650 msec (SD = 85 msec) and for classification in concurrence with letter typing - 843 msec (SD = 121 msec).

These differences are highly significant ($t(16) = 5.93$; $P < 0.001$). Single task performance of digit classification showed no such differences between the two groups. Average single task performance was 675 msec for the tracking group and 652 msec for the letter typing group.

Comparison of tracking performance in sessions 4 and 5: Tracking performance of the same subjects was better on the fifth session when this task was combined with digit classification than on the fourth session when it was performed with letter typing.

Average RMS errors on session 4 were .318 (SD = .67)

Average RMS errors on session 5 were .289 (SD = .46).

A t test showed that these differences were highly significant ($t(8) = 4.21$; $P < 0.001$).

No such differences were found between single task performance levels in the

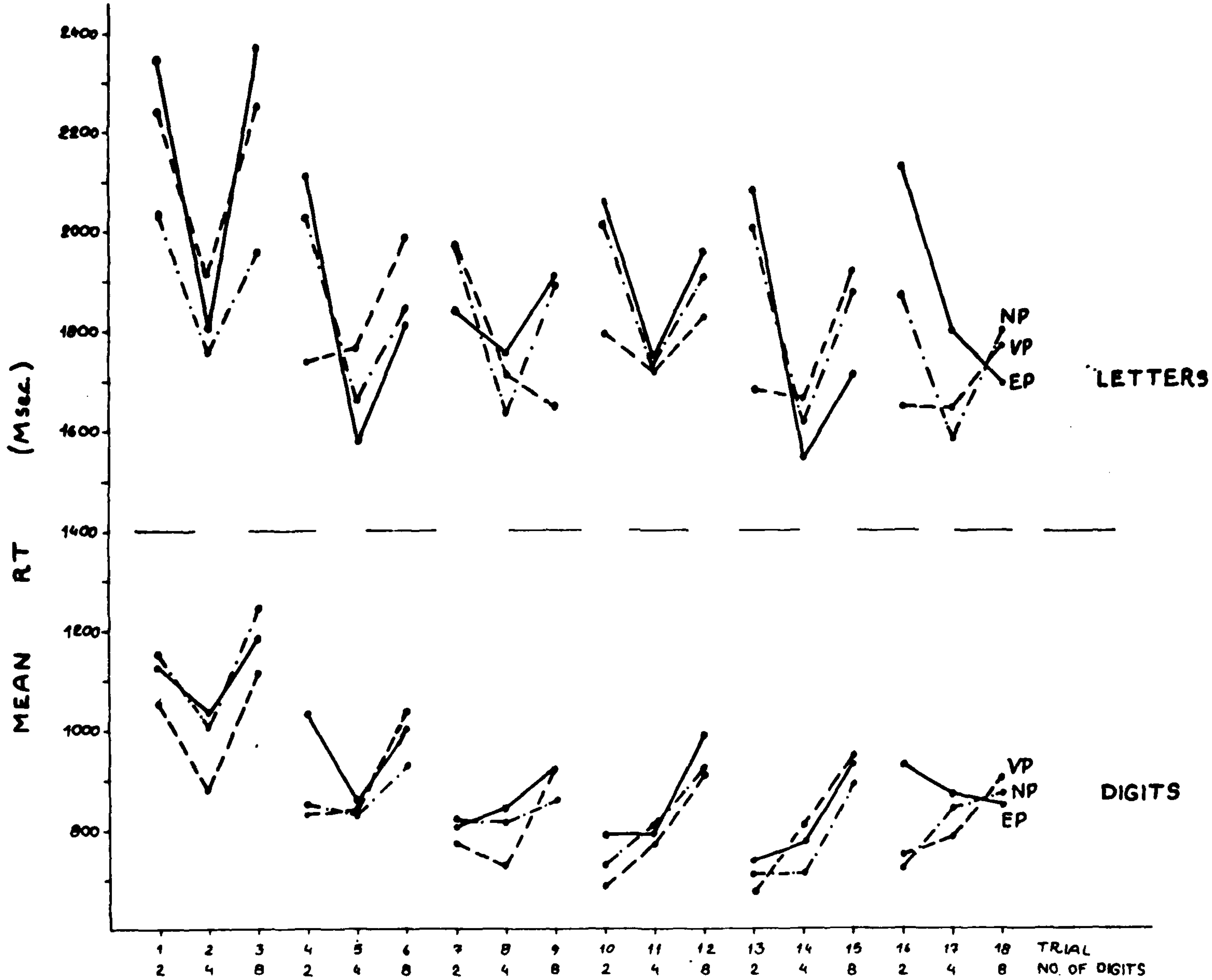


Fig. 8: The effects of difficulty manipulation on letter-typing (a) and digit classification (b) of the three groups during 6 dual task replications (n=9).

two sessions. Average RMS errors were .235 and .227 in sessions 4 and 5 respectively ($t(8) = 0.83$).

Letter typing performance in sessions 4 and 5: Letter typing performance was remarkably better when performed with tracking (session 4) than with digit classification (session 5):

Average response time on session 4 was 1175 msec, SD = 183 msec

Average response time on session 5 was 1815 msec, SD = 306 msec.

These large differences were also highly significant ($t(8) = 9.03$; $P < 0.001$).

DISCUSSION

Separate training and initial dual-task performance

The design of the present experiment required prolonged training periods on both experimental tasks. Hence, the samples that could be employed were relatively small and matching of subjects to control some of the individual variations was inevitable. It is important to note that matching was successfully accomplished, as shown in Tables I and II, without eliminating any subject from the sample. In addition, although only single task measures were employed for matching, initial performance under dual-task conditions showed no initial differences in performance between the three groups at the beginning of training (Table III).

It can be seen (Tables I, II, III) that the joint performance of tracking and letter typing caused a large decrement in letter typing performance, as compared with single task letter typing at the end of the first experimental session. This decrement indicates initial interference or competition for common resources between the two tasks. Tracking performance cannot be compared in the same manner, because initial training

on this task was adaptive.

Effects of priorities manipulation

Manipulation of priorities in the VP group had a large and significant effect on the performance of both tasks (Figure 3). This outcome is consistent with the results of several previous studies, in which a similar technique of priority manipulation was employed (Gopher and North 1974; Gopher and North 1977; Wickens and Gopher 1977; Gopher and Navon 1980; Navon, Gopher and Chillag 1980; Gopher, Brickner and Navon in press). Priority effects in the present experiment were nearly linear on both tasks, indicating strong competition between the two tasks for common resources across the whole range of performance, except for the highest priority level of the letter typing task on which performance did not improve. It seems that this task exhibited some effects of reduced marginal efficiency of resource investment (Navon and Gopher 1979). However, the nonlinear portion was small in comparison with other dual-task combinations on which the benefit of one task from the released resources of the concurrently performed task was much smaller. For example, horizontal and vertical pursuit tracking (Gopher and Navon 1980), pursuit tracking and digit classification (Navon, Gopher and Chillag 1980), and one-dimensional compensatory tracking with self-paced digit processing (North 1977).

The nature of tradeoff between tracking performance and letter typing is best presented by the Performance Operating Characteristics (POC) between the tasks (Figure 4) which is nearly linear except for the highest priority level of letter typing. Note that single task performance is only moderately better than the high priority dual-task performance levels. These findings suggest that the locus of task interference in this experiment is mainly resource related. That is, the two tasks compete for common

resources with little or no effects of structural, or concurrence cost factors (Navon and Gopher 1979).

A similar pattern of priority effects on the same task combination was obtained by Gopher, Brickner and Navon (in press) who investigated the effects of different types of typing difficulty parameters (motor, cognitive) on its joint performance with two-dimensional pursuit tracking. They concluded that typing and tracking compete mainly for a motor-related resource and not for cognitive resources.

Effects of training with priority changes and augmented feedback

The results of differential training of the three experimental groups were rather surprising and contradicted several of our initial expectations. The VP group achieved the best performance levels on both tasks. This is demonstrated by comparing all trials on which the three groups received equal priority instructions (see Figure 5a, b) and also by comparison of the average performance levels at the end of the practice period (Table IV). Performance levels of the EP and NB groups approached those achieved by the VP group on the lowest priority conditions. These differences are surprising because it was expected that the EP and NB groups, which practiced under more unified and consistent conditions, and were relieved from the requirement to reallocate resources in unequal shares, would develop some level of task automaticity (Shiffrin and Schneider 1977; Logan 1978, 1979), or task integration (Neisser 1977), which will show in improved joint performance relative to the VP group.

Furthermore, the superior performance ability of the VP group, which was developed during the practice period, did not disappear or diminished when the three groups were transferred to a common difficulty manipulation without feedback indicators. The VP group revealed better performance in

two aspects of this transfer condition: first, dual-task performance was reliably better on both tasks, indicating that the time-sharing skill acquired by the VP group during differential training, transferred positively to the new experimental condition. Secondly, the VP group succeeded considerably better than the EP and NB groups in protecting performance against difficulty changes. This later finding cannot be attributed to ceiling or data limitation effect on the high performance levels of the VP group, as evident from the comparison with single task performance levels in this condition. Another important indication that the flat slopes of the VP group indeed result from a better ability to protect performance is the similarity between the slopes of the three groups in single task performance with the change of task difficulty (Figure 6a, b). Thus, the flat slopes of the VP group in view of difficulty changes, reflect a successful adoption of sharing strategy to balance performance. The fact that the VP group was superior to both EP and NB groups enables us to conclude that the differences stem from the exposure to variable priority training and cannot be accounted for by the augmented feedback display.

The on-line feedback appeared to have a positive effect on the acquisition of tracking skills. The EP group revealed better tracking performance during training, and in transfer to a changing difficulty condition. No such differences were revealed in letter typing performance. The differential effects of feedback augmentation on tracking and typing performance may be the result of the basic nature of these two tasks. Tracking as employed in the present experiment was a continuous task, the performance of which demanded continuous error estimation, namely the evaluation of the dynamic differences between target and the controlled element movements. The performance of this task appeared to lack an inherent clear

feedback on the quality of performance. Subjects who were asked informally to evaluate their tracking performance at the end of two-minute practice trials (without feedback) were not able to provide accurate estimates. Tracking performance could therefore greatly benefit from the presence of on-line feedback indicators.

In contrast, letter typing was a discrete task in which new letters were not displayed until the correct code of the previously displayed letter was entered. Subjects had a clear indication of the quality of their performance even without feedback bargraphs. This task could therefore benefit less from the presentation of on-line feedback.

In the fourth experimental session, when feedback indicators were completely removed, the EP group still maintained better tracking levels compared to the NB group. Hence, the on-line feedback not only improved immediate performance but also led to acquisition of improved skills. Tracking differences between the EP and NB groups disappeared in single task performance (Figure 6b). Somehow, augmented feedback helped tracking performance only under time-sharing conditions. When performed singly, subjects seem to have enough available resources to supervise performance and estimate error even without added feedback.

<u>Tracking and letter typing combined with a digit classification task:</u> In the last experimental session half of the subjects in each of the three experimental groups were transferred to a changing difficulty dual-task condition which was composed of one familiar task (tracking or letter typing) and one new task (digit classification). Tracking accuracy scores when combined with the digit classification task were quite similar to those obtained in the fourth session when it was performed with the well-practiced letter typing task (Figure 7a). The differences between groups

were also maintained with the VP group, revealing best performance, followed by the EP and NB groups. However, the magnitude of these differences was considerably smaller than those obtained in the former session. More important is the fact that group and difficulty effects did not interact. Thus, tracking performance in all three groups passively reflected changes in task difficulty, and the VP group was unable to protect performance. A possible interpretation to the reduced group differences is that all groups received equal treatment in the fourth experimental session so that performance differences diminished. The inability of all groups to overcome changes in tracking difficulty may be attributed to the lack of resource competition between tracking and digit classification. Navon, Gopher and Chillag (1980) argued that tracking and digit classification overlap very little in their demand for common resources. Minimal competition is also implied by the high level of tracking performance with digit classification as compared to tracking performance with letter typing. It can be argued that tracking performance could not benefit much from resources released by the concurrently performed digit task and its performance could not be protected from difficulty effects.

Digit classification also revealed strong effects of the difficulty manipulation, but no group differences were obtained. In general, the transfer of subjects from the joint performance of tracking and letter typing to tracking with digit classification was smooth and easy and tracking was performed significantly better with digits than with letters.

It is interesting to compare the concurrent performance of tracking and digit classification in the present study with the results obtained by Navon, Gopher and Chillag (1980) in their investigation. Performance levels on the digit classification task of the present subjects were about

20% better than Navon et al's subjects, although in that experiment subjects had longer and more direct training in the concurrent performance of tracking and digit classification. In single task digit classification, subjects in the present experiment were only 5% better than Navon et al's subjects. Although an exact comparison of the two experiments is not possible because of some procedural differences between them. The results of this informal comparison can be interpreted as an indication that early practice in the concurrent performance of tracking with a letter typing task was a better preparation to a transfer to a tracking and digit classification combination than direct practice on tracking with digit classification. This is of course a speculative suggestion that deserves further investigation.

A second half of the subjects was transferred to a combination of two discrete tasks, the previously practiced self-paced letter typing and the newly-introduced externally-paced digit classification. Performance on both tasks was severely impaired as compared to single task performance or to the joint performance of each of them with tracking (Figure 8a, b). When the difficult version of each task was paired with an easy version of the concurrently performed task, interference between tasks was so severe that the overall effects of the difficulty manipulation on the performance of both tasks had a V shape rather than a monotonic effect (Figure 8). Group differences were not revealed on either task.

In spite of the prolonged training on the letter typing task, both singly and in dual task conditions, there was very little transfer of former training to the performance of the letters-digits combination. The empirical data reveals the existence of strong mutual interference between the tasks and indicates that initial practice did not reduce the sources of this interference. Joint performance of a self-paced and an

externally-paced task requires coordination of the rhythms of performance, processing and response. Tasks that have incompatible rhythms may strongly interfere with each other (Kahneman 1973; Navon and Gopher 1979; Keel, in press). In the present experiment the only way to avoid a conflict between letter typing and digit classification was by adapting the rate of response on the self-paced task to the dictated rhythm of digit classification. This was indeed the strategy adopted by several subjects in the present experiment. They reacted to each digit immediately after its presentation and then responded to one letter. This strategy proved to be quite efficient. However, even those subjects who grasped this principle had difficulties in applying it during the 15 dual-task trials of the present experiment. One cause for such difficulties was that the letter typing task was usually perceived as a more meaningful and interesting task. Another cause was the greater familiarity of this task as compared with the digit classification task. Thus, when a letter and digit were simultaneously presented, subjects had a strong tendency to react first to the letter. Doing so, they frequently missed the digit altogether and scored poorly on this task.

The outcomes of transfer to a new task combination can be summarized as follows: positive transfer was observed on tracking performance when coupled with a new task (digit classification) which was quite similar to the former concurrent task (letter typing), both tasks are discrete reaction time tasks and rely heavily on memory resources. Little or no positive transfer of training was obtained on letter typing when coupled with the digit classification task. Apparently, the combination of classification and typing in contrast with tracking and typing or tracking and classification represent a fundamental change in the nature of the concurrent situation which requires the development of time-sharing

skills that were not acquired during former training.

The concurrent performance of tracking and typing (or digit classification) differs from the joint performance of letter typing and digit classification in several important aspects that may contribute to the differences in performance. Tracking is a continuous task, typing is discrete, their integration under time-sharing conditions may be easier than when the two tasks are discrete. If the two tasks are discrete, a problem of conflicting rhythms may arise.

Another aspect is the type of resources involved. Gopher, Brickner and Navon (in press) showed that tracking and letter typing mainly compete for motor-related resources. In a second study, Navon, Gopher and Chillag (1980) reported that tracking did not compete with digit classification which imposed mainly demands on cognitive resources. Applied to the present situation, the results of the two studies enable some interesting interpretations to be made: transfer of subjects to the performance of tracking and digit classification did not create major conflict for common resources because the overlap between the two was minimal. However, digit classification and letter typing jointly compete for cognitive resources, the use of which was not practiced in earlier training sessions because letter typing and tracking competed mainly for a different type of resources - i.e., motor-related requirement.

Experiment 2 was designed to investigate these questions. Letter typing was paired with digit classification within the same general design employed in the first experiment. Training was conducted employing self-paced versions of both tasks, leading to transfer to externally-paced version and changing difficulty conditions.

EXPERIMENT II

METHOD

Experimental Tasks

Letter Typing: The letter typing task employed in this experiment was identical to the task used in Experiment I. It differed only in the mode of display. Because the tracking task was not used in this experiment, letters were displayed in a fixed location, 1.5 cm left of the center of the screen (see Fig. 9). Typing was performed with the left hand.

Digit Classification: The digit classification task used in Experiment 2 was a self-paced version of the task described in Experiment 1. That is, a new digit was generated by the computer each time the currently displayed digit was classified by the subject or 3 seconds passed with no response. A 100 msec delay between successive digits was added, to enable subjects to identify the change of digits on the screen. Digits were displayed 1.5 cm to the right of the center of the screen (see Fig. 9) and responded to by the two middle fingers of the right hand.

Note the difference between the display procedures of digits and letters. While letters remained on the screen until a correct code was entered (or until 3000 msec have passed), digits disappeared in reaction to any response. This procedure was employed because the response set for digits included only two alternatives.

Average reaction time for correct classifications (CRT), false classifications (FRT), and missed digits (MISS), were recorded. A weighted reaction time score (WRT) was computed at the end of each trial as in the first experiment (equation No. 1), except for the maximal inter-stimulus interval, which was 3000 msec instead of 1500 msec.

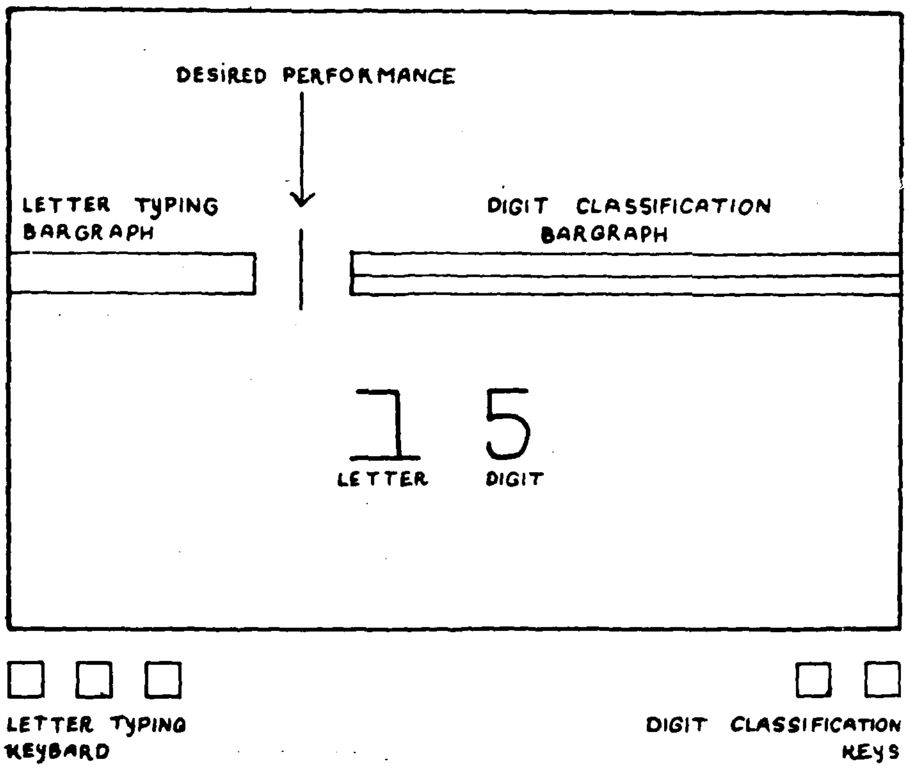


Fig. 9: Subjects display in concurrent performance of tracking and letter-typing.

Insert Figure 9 about here

Priority manipulation by feedback indicators: Subjects could be presented with an on-line, continuous feedback on their performance, as described in Experiment 1. In the present experiment the right side bargraph represented digit classification and the left side bargraph represented letter typing performance (see Fig. 9). At any moment, each bargraph displayed the mean weighted reaction time (WRT) of a ten-trials running window.

Verbal feedback and monetary rewards: As in the first experiment, verbal feedback and monetary rewards were given in all but the first experimental session. At the end of each two-minute trial, the difference between actual and desired *performance* was computed for each task and rewards were inversely proportional to the difference between actual and desired performance. If subjects reached the required performance levels on both tasks, they received 10 Israeli pounds. Reward could be higher if actual performance on both tasks was better than desired performance.

Experimental groups

In the second experiment only two experimental groups were contrasted: a variable priority group (VP) where subjects practiced dual-task performance at five different levels of task priorities, and an equal priority group (EP), in which on-line indicators were presented but only equal task priorities were practiced.

Procedure

Experimental sessions: All subjects participated in six two-hour experimental sessions. No two sessions were held on the same day. The

general experimental design is presented in Table 5.

The first session was devoted to initial familiarization and training on the two experimental tasks. Subjects first practiced until they were able to type all letters twice without error, then they performed twelve two-minute letter typing trials, with the whole set of 22 Hebrew letters, followed by nine trials, in which only the three equal difficulty subsets of 4 letters were presented. On the digit classification task, 6 two-minute trials were interweaved in the letter typing trials. For each trial, a new set of 4 digits was introduced, to avoid development of consistent mapping strategies.

At the end of the first session, subjects were assigned to one of the two experimental groups, based on their basic performance ability.

Sessions II and III were the main training sessions, under varying or equal priorities, including a total of 30 two-minute trials.

In the fourth session, the two groups were transferred to the performance of a letter typing task, together with the externally paced version of digit classification employed in the fifth session of experiment I. To recall, each digit was displayed for 300 msec followed by a 1200 msec interval before the next digit was presented. Fifteen two-minute dual-task trials were performed. In each trial, one of the equal difficulty four-letter sets and a new set of four digits were combined. In addition, three trials of single task digit classification were performed. Feedback indicators were not used during this session, demand levels were given verbally, and subjects received monetary rewards for good performance. Session V was identical to session III, but included only 15 dual-task trials, and served for retraining of the two experimental groups.

Session VI replicated the changing difficult fixed performance

design used in the transfer task of the first experiment. The difficulty manipulation of letters consisted of the sets of 4-difficult, 4-medium and 4-easy letters used in the first experiment. Digit classification difficulty was manipulated using 2, 4 and 8 digit sets. Fifteen two-minute dual-task trials were preceded by three familiarization trials with the three sets of letters. In addition, three single task letter typing trials and three single task digit classification trials were performed - one for each level of difficulty. Feedback indicators were not presented and equal levels of performance were demanded in all difficulty combinations.

Subjects

Twelve male, right-handed subjects, aged 19-25, participated in the experiment - six in each experimental group. Subjects were paid hourly rates in session I and earned monetary rewards for their performance during sessions II-VI. None of these subjects participated in the first experiment.

RESULTS

Initial Training

Letter typing: Average response times and standard deviations on the last six letter typing trials of the first session are presented in Table 6. On each trial, one of the three equal difficulty letter sets was presented.

Table 5: General Design of Experiment II

Session	Experimental Group Treatment		Description
I	Identical		Separate training of letter typing and digit classification
II	Identical		Initial dual-task training without bargraphs (8 trials)
	Differential	VP -	Dual task with varying priorities (10 trials)
		EP -	Dual task with equal priorities (10 trials)
III	Differential	VP -	Dual task with varying priorities (20 trials)
		EP -	Dual task with equal priorities (20 trials)
IV	Identical		Transfer to letter typing with externally-paced digit classification (15 trials)
V	Differential		Differential dual task retraining (15 trials, same as III)
VI	Identical		Transfer to a changing difficulty combination with fixed performance levels (5 replications of 3 difficulty manipulations, 3 single trials on each task)

Table 6: Average RT and SD (msec) for letter typing at the end of the first experimental session.

		Experimental Group	
		VP(N=6)	EP(N=6)
Letter Typing	$\bar{X}$	1338	1320
	SD	302	249

Differences between the groups were small and insignificant, reflecting the results of matching.

Digit classification: Weighted reaction (WRT) measures on the last three trials of digit classification in the first experimental session are presented in Table 7. A different set of 4 digits was employed in each of these trials.

Table 7: Average WRT scores and SD (msec) of digit classification at the end of the first experimental session

		Experimental Group	
		VP(N=6)	EP(N=6)
Digit Classification	$\bar{X}$	759	776
	SD	116	101

Here again, the similarity between groups is the result of matching.

Initial Dual-Task Performance

At the beginning of the second experimental session, both experimental groups performed eight dual-task trials without feedback indicators. Table 8 presents the results of these trials.

Table 8: Average performance of letter typing and digit classification (msec) on the first eight dual-task practice trials

		Experimental Group	
		VP	EP
Letter Typing	$\bar{X}$	2294	2249
	SD	866	660
Digit Classification	$\bar{X}$	1715	1619
	SD	377	308

Differences between groups in letter typing performance were negligible. Differences on the digit classification task were somewhat larger in favor of the EP group, but these differences did not reach statistical significance ($t(5) = .69$). It can therefore be concluded that the two groups did not differ initially in either single or dual task performance.

Note that the differences between single and dual task performance in both groups and both tasks are relatively large.

Priority Manipulation Effects

As in the first experiment the effects of priorities manipulation on the performance of both tasks in the VP group were large and significant. A separate analysis of variance was performed for the data of the third and fifth meetings to evaluate the effect of this variable. F values for letters in session III were: $F(4,20) = 6.83$ ($P < 0.01$), and for digits $F(4,20) = 12.92$ ($P < 0.001$). In session V: for letter typing performance $F(4,20) = 4.13$ ($P < 0.025$) and digit classification $F(4,20) = 11.30$ ($P < 0.001$).

The effects of priority changes on performance of both tasks in the two experimental sessions are depicted in Fig. 10. In spite of the big improvement in average performance between the two sessions, the pattern of the priority effects on both tasks did not change much. Digit classi-

Insert Figure 10 about here

fication performance increased linearly with increased priorities, while letter typing performance seemed to asymptote at the equal priorities level, with no further improvement with increased priority. Joint performance on the two tasks is plotted as a POC curve in Figure 11. The convex curves reveal the asymmetric effects of priority changes on the two

Insert Figure 11 about here

tasks. While digit classification improved when resources from the low priority letter task were released, letter typing did not gain from released resources from decrementing digit performance and did not improve beyond the level of equal priorities.

Note the large differences between single and dual task digit classification as compared to the more moderate differences in letter typing.

Effects of differential training under time-sharing conditions

Figure 12 presents average performance measures of letter typing and digit classification in nine successive trials in which both experimental groups performed the two tasks with equal priorities. These trials were performed at the second, third and fifth experimental sessions.

Insert Figure 12 about here

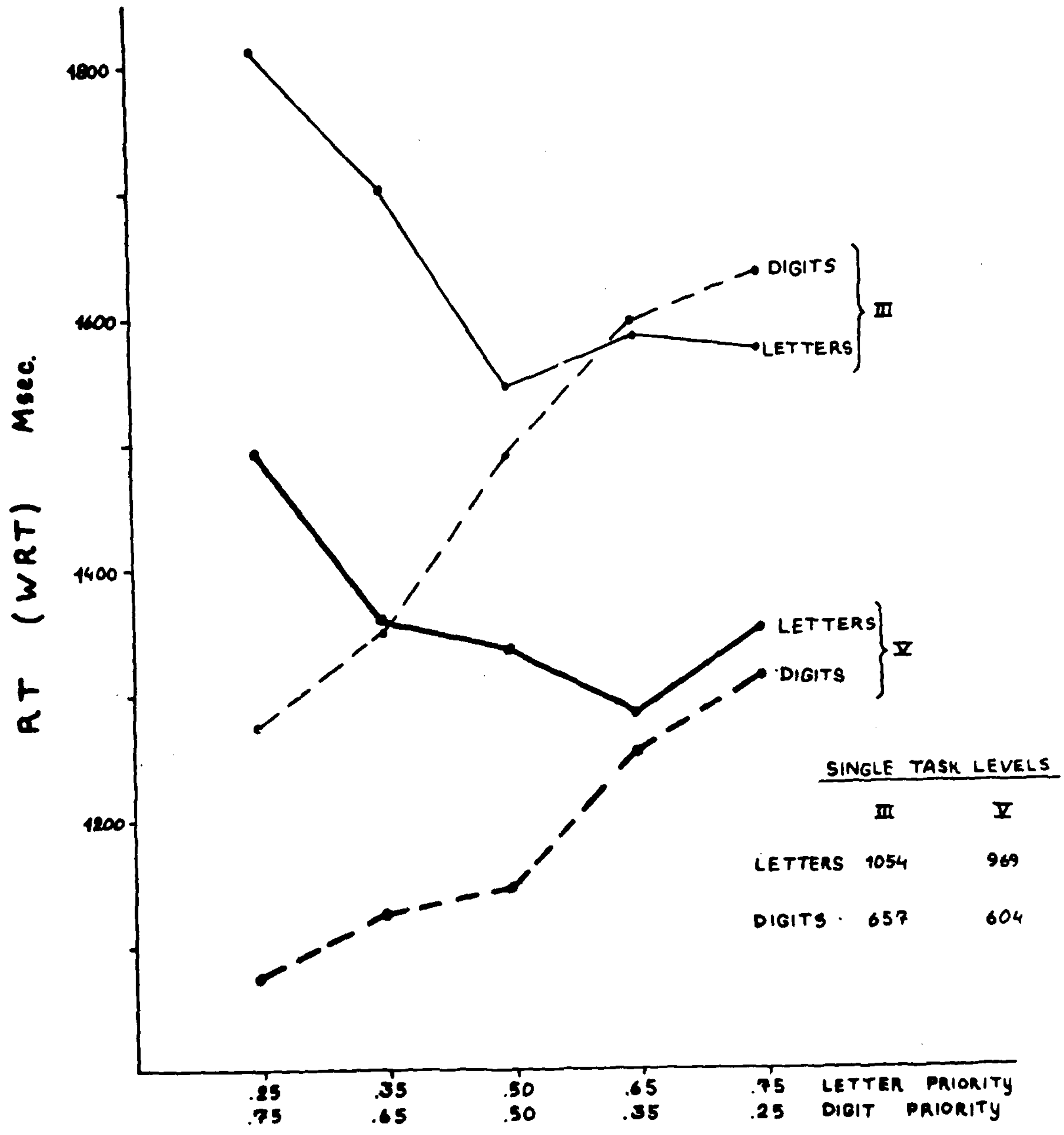


Fig. 10: Performance of letter typing (RT) and Digit classification (WRT) as a function of priority levels, on session V full line) and session III (dotted line) (N=9)

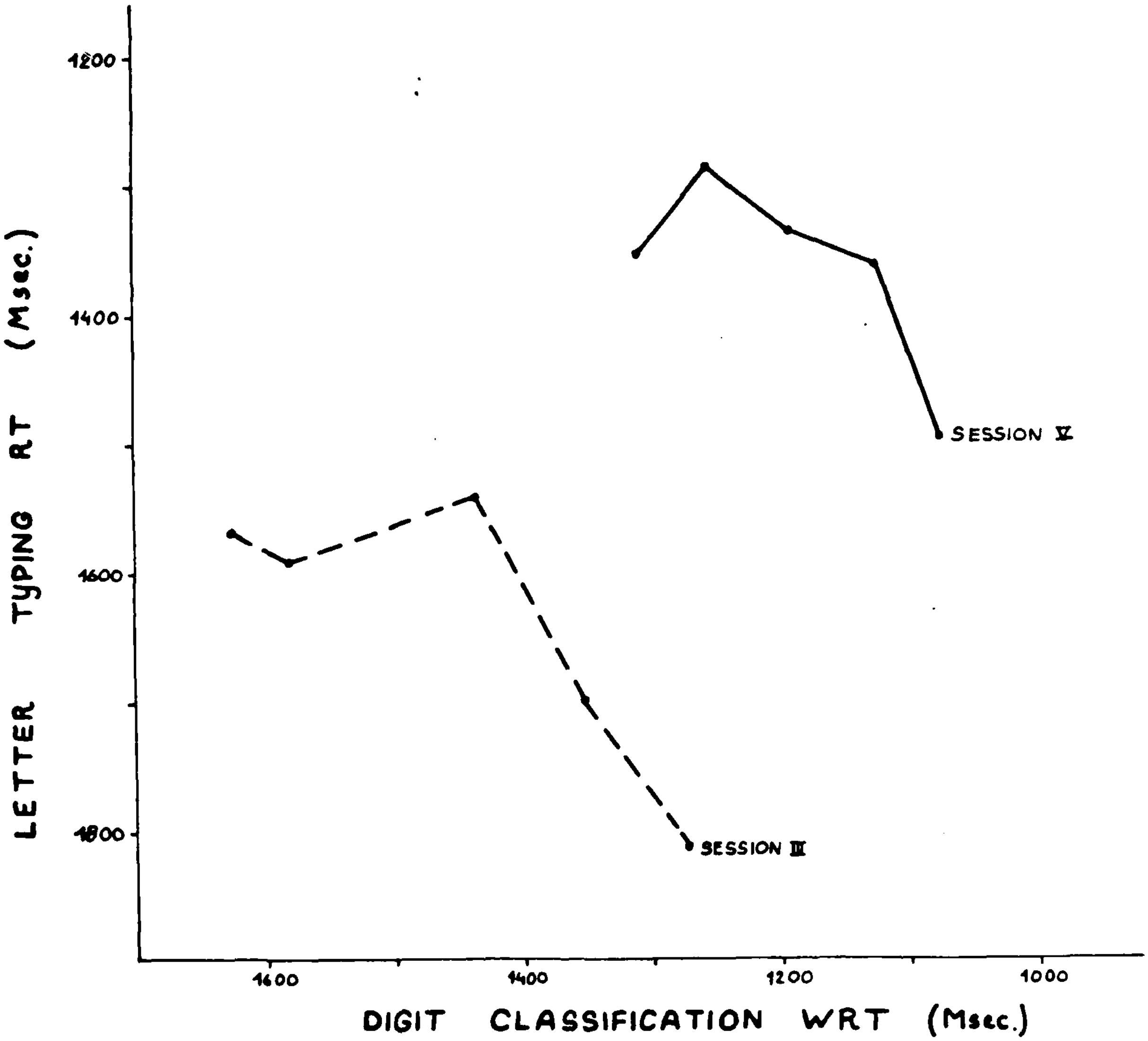


Fig. 11: POC's depicting performance tradeoffs between letter-typing and digit classification in experimental sessions III (dotted) and V.

It can be seen that consistent differences in response time for letters, in favor of the VP group, emerged in the third experimental meeting. The differences were even larger on the fifth session. Digit classification performance did not reveal such differences.

As in the first experiment, the results of matched subjects were treated as correlated observation and group effects were treated as repeated measures. A two-way analysis of variance (group x training) was conducted. On both tasks only training effects reached statistical significance. For digits $F(8,4) = 18.19$ ($P < 0.001$) and for letters ($F(8,4) = 11.10$) ($P < 0.001$). Group effects were not significant. For digits $F(1,5) = 0.28$ and for letters $F(1,5) = 2.94$.

The inconsistency between the analysis of variance results and the apparent group differences in letter typing performance as plotted in Figure 12 is the result of the small samples and the large intersubjects variability. A direct comparison of the matched pairs of subjects in the two experimental groups revealed that in the two extreme pairs, those who reached the highest and lowest levels of performance on letter typing, the EP subjects were same or better than the VP subjects, while in all middle four pairs with average performance, the VP subjects were remarkably better. Based upon this comparison, we may speculate that for the two extremes (i.e., best and worst performer), the priority manipulation was not powerful enough to counteract inherent performance capabilities. In the four middle pairs, however, the VP group was better trained. It should be noted that a within-pairs comparison of the group effects by a t test yielded significant t values ($t(5) = 2.05$; $P < 0.05$).

A similar analysis was conducted for all dual task trials on the third and fifth sessions. On the third sessions only training effects

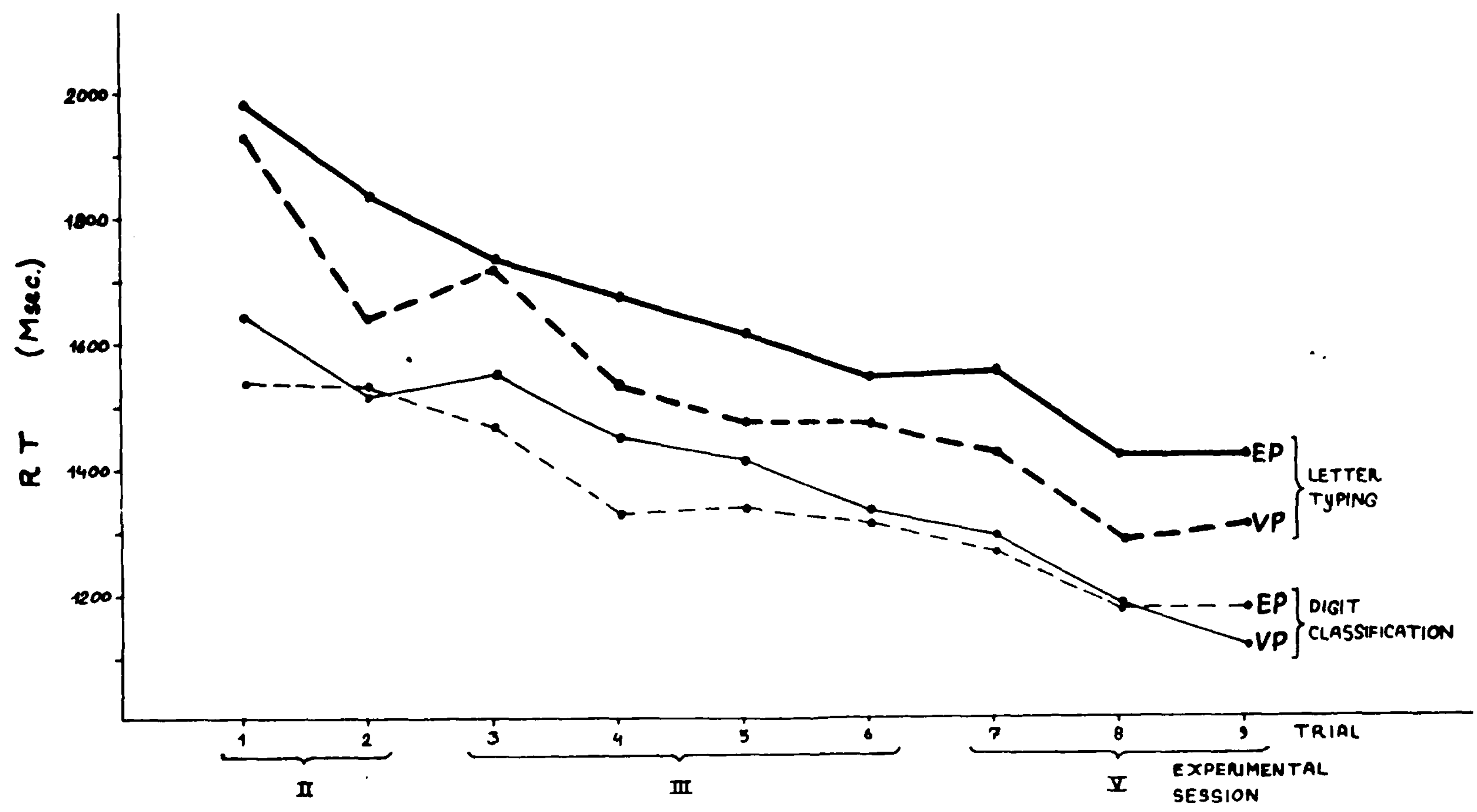


Fig. 12: Average response times for letters and digits (WRT) on nine dual-task, equal priorities trials (N=12)

reached statistical significance, for letters $F(3,15) = 17.99$ ($P < 0.001$) and for digits $F(3,15) = 16.68$ ($P < 0.001$). On the fifth session training effects were much smaller, and reached statistical significance only for the digit task ($F(2,10) = 5.84$; $P < 0.05$). Differences between the VP and EP groups in letter typing performance were again below the level of significance ($F(1,5) = 2.84$). The differences between groups showed precisely the same pattern revealed in the previous analysis. Again, a separate analysis by a t test yielded significant between-group differences ($t(5) = 2.31$; $P < 0.05$). Single task trials performed in each of these sessions did not reveal differences between the groups in letter typing or digit classification. Single task results are summarized in Table 9.

Table 9: Single task performance of letter typing and digit classification (msec) in experimental sessions III and V.

Session	III		V	
Group	VP	EP	VP	EP
Letter Typing	1152	1026	944	917
Digit Classification	658	660	604	620

In summary, dual task training under variable priorities resulted in better performance for this group in letter typing, and the difference between groups increased with the progress of training Digit classification did not show similar effects of training

Letter typing with externally-paced digit classification

On the fourth experimental session, both groups were transferred to a condition in which letter typing was performed concurrently with an

externally-paced version of the digit classification task. Feedback indicators were not employed in this session. Figure 13 depicts the differences between the VP and EP groups under this condition, which, in the first experiment, led to a severe impairment of performance on both tasks.

Insert Figure 13 about here

The most striking result in Figure 13 is the consistent advantage of the VP group in the performance of the newly-introduced externally-paced digit classification task.

A two-way analysis of variance (group x training) was conducted to analyze these results. For letter typing only the training effect was significant - ($F(4,20) = 8.25$; $P < 0.001$. For digit classification, training effect was again significant - ($F(4,40) = 2.23$; $P < 0.05$, and group differences were also highly significant $F(1,5) = 19.04$; $P < 0.01$. Differences between the groups in single task performance were not reliable on either task.

Transfer to a changing difficulty situation with fixed performance requirements: In the sixth experimental meeting, both groups were transferred to a dual task performance with commensurate difficulty changes on the two tasks. Subjects were instructed to protect performance and maintain a constant level under all conditions. Feedback indicators were not displayed. Letter typing and digit performance under these conditions are plotted in Figure 14a, b.

Insert Figure 14a, b about here

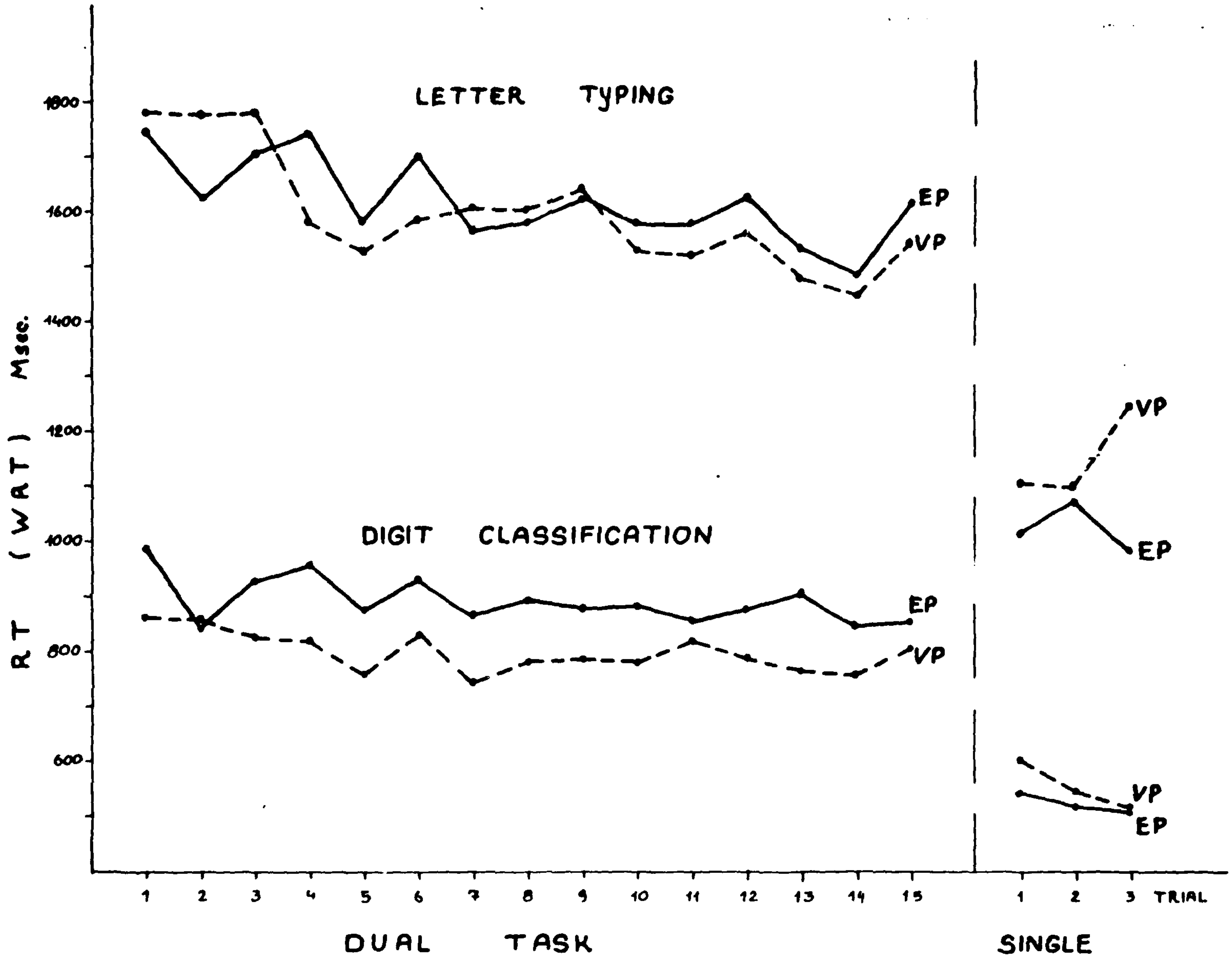


Fig. 13: Performance of letter typing (dotted lines) and externally paced digit classification (full-line) concurrently and singly.

Performance on both tasks revealed the superiority of the VP over the EP group. The differences between groups were bigger and more consistent on the letter typing task. The VP group was also to be more successful in protecting performance against difficulty changes. A three-way analysis of variance (group x training x difficulty) was conducted to test the significance of these results. For letter typing, both training and difficulty effects were significant ($F(4,20) = 3.39$; $P < 0.05$, $F(2,10) = 17.36$; $P < 0.001$, respectively). Group effects reached only the 10 percent level of significance ($F(1,5) = 4.68$; $0.05 < P < 0.10$). In a separate analysis of the group effect, using a t test, these differences were significant at the .02 level ($t(5) = 3.42$; $P < 0.02$). For digit classification only the main effects of task difficulty reached statistical significance - $F(2,10) = 5.14$ ($P < 0.05$). The interaction between training and difficulty was also significant - $F(8,40) = 6.34$ ($P < 0.001$). Single task performance did not show reliable difference on either task.

Task interference between letter typing and digit classification, which was strong during the whole experiment, was much strengthened when the difficult version of either letter typing or digit classification was used. As a result, the effect of the difficulty variable on both tasks was not monotonic and the tasks were best performed in the medium difficulty combination. This data is summarized in Table 10.

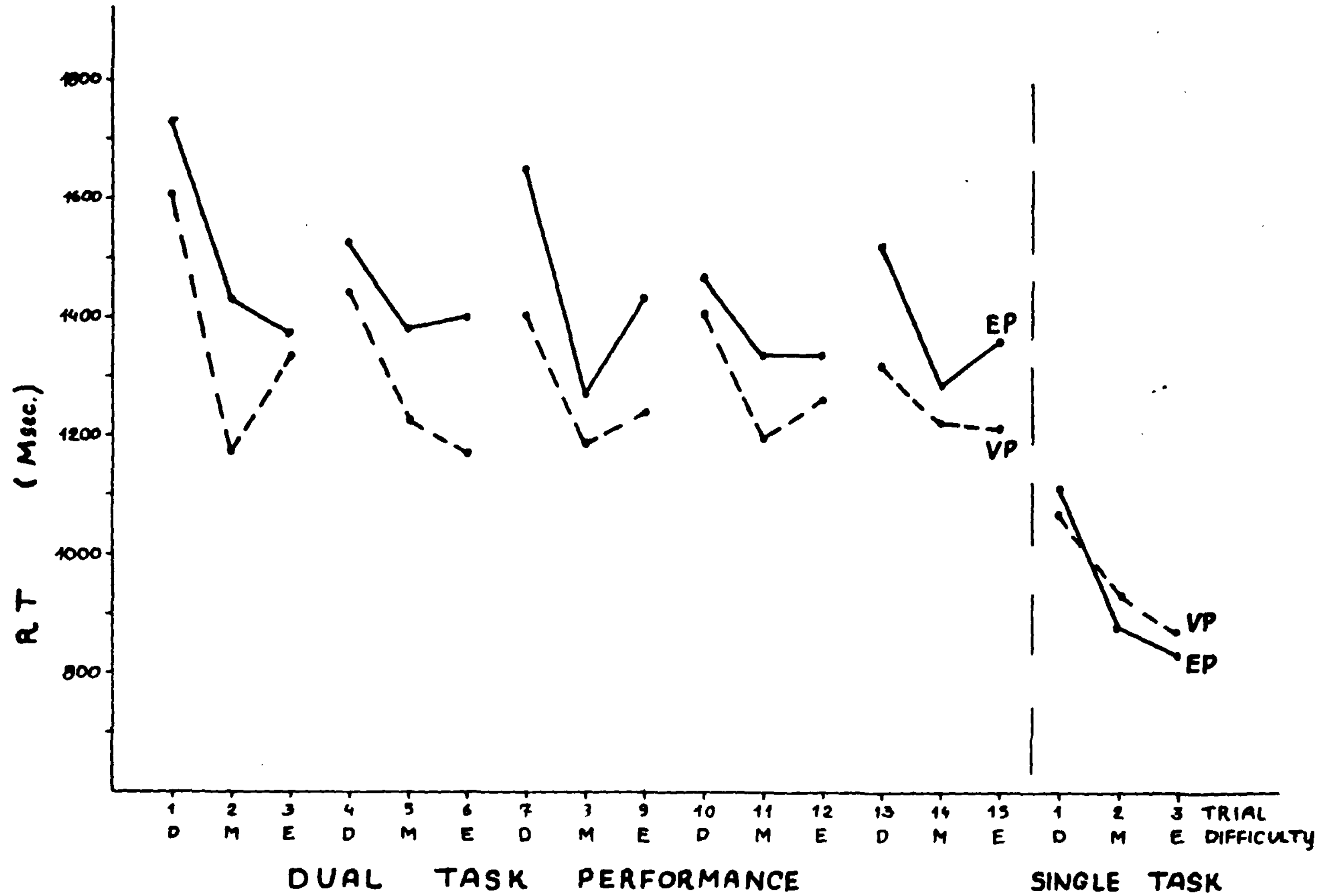


Fig. 14a: Dual and single task letter typing performance on difficulty (D), medium (M) and easy (E) sets of 4 letters (N=12).

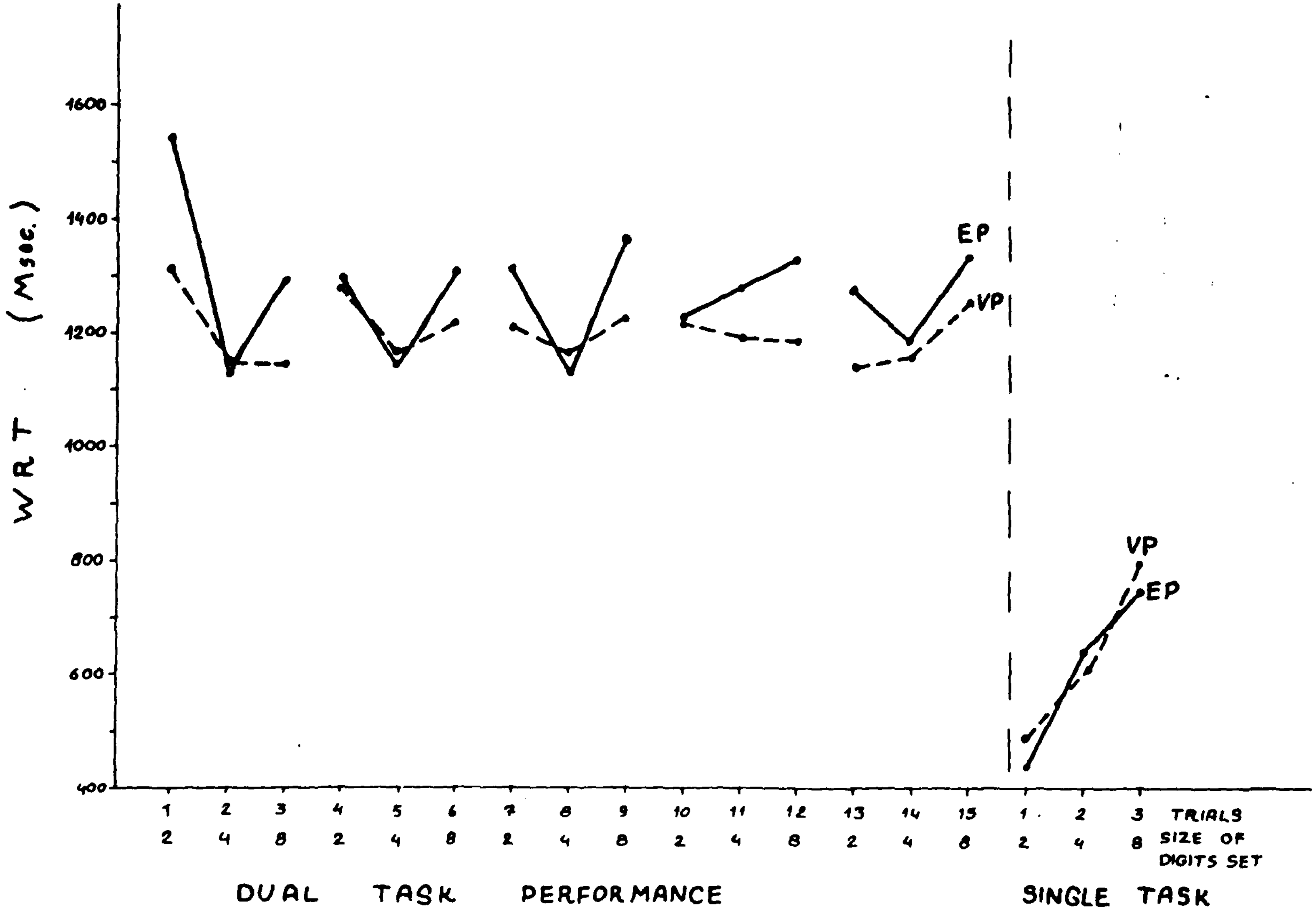


Fig. 14b: Dual and single task digit classification on three sizes of digit sets (2,4,8) N=12.

Table 10: Dual task response times (msec) on letter typing and digit classification, as a function of task difficulty

letter typing	difficult	medium	easy
	1519	1294	1323
digit classification	1280	1166	1260
	easy	medium	difficult

Comparison of letter typing performance on experiments I and II

Letter typing performance with tracking (experiment I) was compared to letter typing with digit classification. The comparison was conducted on the last 20 dual task trials of the third experimental session of each experiment, that is, at a point where subjects had a similar amount of practice in this task.

Mean response time to letters with tracking was 1120 msec (SD 215 msec)

Mean response time to letters with digit classification was 1644 msec (SD 407 msec)

This difference was highly significant: $F(1,10) = 14.34$ ($P < 0.01$).

DISCUSSION

Separate Training and Initial Dual Task Performance: As in the first experiment, subjects in the two experimental groups were matched based upon their single task performance ability. Initial single task performance scores of the two groups were very similar on both tasks and indicated that matching was successfully accomplished (Tables 6 and 7). Initial dual task performance (Table 8) showed large performance decrements and wide variability on both tasks, demonstrating strong mutual interference between the tasks. However, these decrements affected equally both groups

and group differences remained small and insignificant in dual as in single task performance.

Manipulation of Priorities: As in the first experiment, the manipulation of task priorities in the VP group had a large and significant effect on the performance of both tasks. In the present experiment training with varying priorities was conducted both in the third and fifth experimental sessions. We can therefore evaluate changes in the effect of this manipulation with training. The POCs for the two sessions plotted in Figure 10 show that in spite of the marked improvement in performance on both tasks, the shapes of the PRF and POC curves remained the same in both sessions. Digit classification performance varied almost linearly with the change of priorities, while letter typing changed very little beyond the level of equal priorities, revealing data limitations or a fast reduction in the marginal efficiency of resources (Navon and Gopher 1979).

It is interesting to note that the range of the priority effects on performance is larger in the third session. In a first thought, this difference appears to contradict the initial expectation that trained subjects will be better able to cope with the requirement to change task emphasis, which may constitute a task by itself. However, a closer examination of these curves may reveal that the larger range of the priorities effect in the third session mainly result from larger decrements of performance at the low priority levels. Subjects in the third session tried to concur with the instructions to decrease performance and release resources, but were not able to balance their performance decrements and decreased performance more than required. In the fifth session, actual performance scores in the low priority conditions were much closer to the demand levels than in the third session. In addition, the effect of priorities on letter typing was somewhat more monotonous. We may speculate that

large effects or priorities do not necessarily indicate better coping ability. It is possible that practice may improve subjects' ability to carry out accurately priority instructions in the lower region more than in the higher region of performance.

Letter typing and digit classification in the present experiment were shown to compete for common resources (Figure 10). However, performance tradeoff between the tasks was not symmetrical. While digit classification benefitted from resources released by the letter typing task, typing could not improve beyond the level of equal priorities. The resulting performance operating characteristics (POC - Figure 11) were highly convexed in their lefthand part and were almost linear on their righthand wing. This pattern was similar in both sessions III and V.

Performance decrements from single to dual task conditions were large on both tasks, suggesting the existence of a strong factor of mutual interference due to sources which are not resource relevant, but belong to concurrence cost (Navon and Gopher 1979) or structural interference (Kahneman 1973). This issue will be discussed in detail in the general discussion.

It is interesting to contrast the relatively small improvement in single task performance on sessions III and V, to the large improvement in dual task performance (Figure 10). It is evident that training contributed primarily to the improvement of dual task coordination.

<u>Training under variable priorities</u>

Training under variable priorities led to better performance only on the letter typing task. Classification performance improved similarly in the EP and VP groups. Group differences in letter typing performance increased with training and were largest at the end of practice (Fig. 12).

Recalling the strong and monotonous effects of priority changes on digit performance, it is somewhat surprising that difference between groups were revealed only in letter typing. One possible interpretation for these findings is that subjects tended subjectively to put more emphasis on letter typing performance. Letter typing was a more complex, interesting and meaningful task for the subjects. Hence, resources released with training as a result of improved time-sharing strategies were primarily invested in letter typing performance. An alternative interpretation is that letter typing, which appears to be a more complex task both at the processing side and on the response selection end, may enable a wider and more flexible selection of allocation policies (Navon and Gopher 1979) or response strategies such that performance under time-sharing conditions may be better optimized. Choice of alternative performance strategies may be much more limited for digit classification performance.

It is interesting to note that in equal priority trials, response times for letter typing and digit classification were much closer to each other in the VP group than in the EP group (see Figure 12). This trend suggests that dual-task performance of the VP group was more balanced and that subjects in this group tended to employ an alternating response strategy (Damos 1977) responding first to one task then to the other, while the EP group tended to adopt a massed strategy - emitting a series of responses on one task and then on the other task.

Letter typing with externally-paced digit classification

The most important finding in the transition to this condition, which in the first experiment caused performance on both tasks to collapse, was the consistent and significant advantage of the VP group over the EP group in performance of digit classification. The differences between the VP and

EP groups in letter typing that were so apparent at the end of the third training session vanished completely (Figures 12, 13). How can these results be accounted for?

Recall that when digit classification was externally paced, a digit was presented for 300 msec, followed by 1200 msec interstimulus interval. The only efficient response strategy to interweave this task with the self-paced letter typing task was to respond to the digit immediately upon its presentation and then turn to attend to the letter task. Any other response strategy would lead to omissions (misses) of digits (except for a simultaneous response strategy which was not exhibited by any of the subjects at this level of training). Thus, in the externally-paced version, the digit classification task can be considered as being "primary" in the sense that it should be responded to first. Development of such a response mode required a change from the strategy developed when both tasks were self-paced.

Successful transfer from self-paced to externally-paced digit classification demanded therefore sufficient flexibility to rapidly adopt a different response strategy, and again the VP group was the one that developed such a strategy faster and more efficiently. This outcome is important because it implies that the superiority of the VP group, that during training was revealed only in typing performance, was not task specific but could be generalized to the performance of the other task when it became more demanding. Note, that the performance differences between the VP and EP groups remained constant throughout the 15 trials of the session, indicating that group differences were already well established at the end of the former experimental session and were persistent enough to hold during the two hour session.

It appears that initial training under variable priorities and self-paced versions of both tasks prepared subjects better for coping with the

demand to coordinate the performance of a self-paced and an externally-paced task, a requirement which was hard to cope with in the first experiment when the combination was introduced after initial training of letter typing with tracking.

Transfer to a changing difficulty situation with fixed performance requirements

The last session of the second experiment replicated the fourth session of the first experiment. Subjects were required to maintain fixed performance levels in view of commensurate difficulty manipulations of the concurrently performed tasks. Differences between the VP and EP groups in average performance levels appeared again in a letter typing task, although both groups were equally unsuccessful in protecting performance from manipulation of task difficulty (Figure 14a). There were no reliable group differences on the digit classification task but the slopes of performance changes as a result of difficulty manipulation in the VP group seem to be flatter than those of the EP group (Figure 14b) (although the interaction between group and difficulty effects did not reach statistical significance). It appears that the digit classification task could benefit more from resources released by decreasing performance on the letter typing task than vice versa. Such a conclusion is consistent with the performance resource functions of the two tasks depicted in Figures 10 and 11. We have argued in a previous paper (Gopher, Brickner and Navon, in press) that letter typing performance requires at least a motor-related resource and a cognitive resource (or resources). Digit classification, on the other hand, appears to rely mainly on memory resources. We can speculate that reduced requirements on the letter typing task release at least some amount of cognitive resources that could be directly applied to the enhancement of

digit classification performance, while improved letter typing depended mainly on a motor-related resource, which was not released by reducing performance demands or reducing the difficulty of digit classification.

The strong interference between the two tasks, particularly when a difficult version of either of them was presented, caused non-monotonous effects of difficulty on joint performance (Table 10). As a result, joint performance at the medium-medium task combination was better than the easy-difficult and difficult-easy combinations. Nevertheless, the effects in the present experiment were not as strong as in the last session of the first experiment and the differences can probably be attributed to the better practice of subjects in the present experiment.

GENERAL DISCUSSION

Taken together, the results of the two experiments demonstrated that training under variable priority conditions may lead to improved performance capability in several aspects of the time-sharing situation. First, the general level of performance achieved by the VP subjects at the end of training was better than the level reached by the EP or NP groups. Secondly, subjects trained under variable priorities were better able to protect performance in transfer conditions when task difficulty was varied. Finally, these subjects revealed better ability to generalize their acquired skills to time-sharing conditions that included a new component. The above three effects were not revealed unanimously in all task combinations and on every experimental condition; but the differential effects of priority changes as a training variable may highlight some important parameters of the tasks involved, the nature of the manipulation, and the structure of attentional resources. These are the major topics of interest in the present discussion.

In the introduction section, a number of possible explanations to the effects of practice on dual-task performance were discussed. One explanation was that concurrent performance is enhanced because of the reduced resource demands for the performance of each task by itself. Such a reduction can possibly account for part of the marked improvement in time-sharing performance observed in the present experiments during practice. However, this factor would equally affect all experimental groups and cannot account for the differences between the groups. This argument is strengthened by the findings that the differences between groups appeared only in dual-task performance and disappeared in all single task conditions.

A second interpretation of the effect of practice on dual-task performance is that performance under time-sharing conditions requires organization, coordination and scheduling of tasks. Coordination consumes resources primarily at the early stages of training and may compete with the actual performance of tasks. Applying this argument to the present experiments, we may argue that coordination of performance with the additional requirement to vary task emphasis should be more demanding than performance under one simple priority condition. Thus, the EP and NB groups would be expected to be better than the VP group at the beginning of training and the differences should gradually diminish with training, until equal performance levels are achieved when coordination strategies have been developed for all task combinations. At that stage, the coordination processes would not impose additional demands on the limited pool. This scenario is contrary to the results of the present experiments, where all groups were equal at the beginning of dual-task training, with a growing difference in favor of the

AD-A118 558 TECHNION - ISRAEL INST OF TECH HAIFA CENTER OF HUMAN--ETC F/G 5/9
IMPROVING TIME-SHARING PERFORMANCE BY ENHANCING VOLUNTARY CONTR--ETC(U)
FEB 81 M BRICKNER, D GOPHER AFOSR-77-3131
UNCLASSIFIED HEIS-81-3 AFOSR-TR-82-0633 NL

2 OF 2
AD A
118558

END
DATE
FILMED
09-82
DTIC

VP group as training proceeded.

Effects of practice and reduced demands for processing resources are frequently linked with the notion of task automaticity (Shiffrin and Schneider 1977; Schneider and Shiffrin 1977; Logan 1978, 1979). When automated, task performance does not require attention control, and responses are believed to be triggered directly by the stimulus (Posner and Snyder 1975; Logan 1979, 1981). Development of automaticity is argued to be facilitated when a task is simple and practiced under consistent conditions (Shiffrin and Schneider 1977). In the present experiments the NB group was the one that was closest to the simple and consistent task definitions. Although even this task was remote from the "consistent mapping" concept of Shiffrin and Schneider (1977) because stimulus sets varied from trial to trial on both letter typing and digit classification tasks. Still, it is clear that an interpretation which emphasizes the development of automatic response modes is inconsistent with the finding that the group which experienced the most variable practice conditions (VP) achieved the highest levels of performance.

Integration is another construct employed to explain improved time-sharing performance with practice. This concept has been introduced by those who argue that practice causes qualitative changes which alter the entire nature of concurrent performance (Neisser 1976; Hirst, Spelke, Reaves, Caherack and Neisser 1980). Integrated tasks lose their separate, independent identities and form a new whole. In the present experiments the use of variable priorities and separate bargraphs for each task component forced subjects to maintain the identity of each task element rather than encouraging integration. It is again the NB group which practiced without bargraphs and priority changes which received ~~more~~ favorable conditions for the development of task integration and could therefore be

expected to reach higher levels of performance,contrast to the actual findings.

Hirst et al (1980) had their subjects practice text reading with simultaneous writing of dictated list of words. After prolonged period of practice subjects succeeded to perform the two tasks together at the same level that each of them was performed separately. Ingenious selection of reading texts and comprehension tests enabled these investigators to reject simple between-tasks alternation strategies, or traditional notions of task automation, as plausible interpretations of their results. Their interpretation emphasizes changes in the approach of subjects to the performance of tasks which enabled them to detect new stimulus constellations and execute new patterns of action. They argue that division of attention should be considered as a skill and its acquisition studied accordingly. This view is closest to the interpretation of improved time-sharing performance in terms of improved voluntary control over processing resources, and enables to propose an interpretation framework that can account nicely for the results of the two experiments. A key process in this explanation is the development of the "internal model".

Throughout the sessions of dual-task practice, each subject can be construed to develop some internal representation of the impact of his efforts on joint performance. In terms of the "Economy of the Human Processing System" (Navon and Gopher 1979) he is assumed to develop a performance operating characteristic (POC). From this POC he can extract the performance resource function of each task. When subjects are exposed to dual-task performance with one priorities combination only, they become familiar with just one single point on the POC and can infer only a single point on each PRF. It is possible, of course, that subjects in the EP and NB groups spontaneously explored more than one task combination.

However, they could hardly be expected to be able to develop a coherent concept of their performance-resource relations. In contrast, the VP group experienced five different combinations of task priorities, with on-line feedback on performance. This experience provided subjects with a rich data-base to establish effective internal model of the returns of their resource investments.

When transferred to a changing difficulty situation which required subjects to maintain fixed performance levels, the established internal model of the variable priority group may have enabled subjects in this group to examine several alternative allocation policies and select the most efficient policy in order to optimize performance. The EP and NB groups could not rely on such a model when developing their own coping strategy.

The efficiency of a well-established internal model was further demonstrated on some of the transfer sessions to new task combinations. In the first experiment the VP group was superior to the EP and NB groups in the performance of a familiar tracking task when it was combined with a newly introduced digit classification task. No differences between the groups were observed on digit classification performance, a task for which none of the groups had the opportunity to develop an internal representation In the second experiment the VP group was better than the EP group on transfer from a self-paced to an externally-paced version of the digit classification task. It seems that in both experiments the greater acquaintance of the VP group with alternative performance-resource combinations enabled subjects to be more flexible in adapting to new task combinations. The benefit could be direct, that is, by selecting one of several performance strategies from those experienced previously. Or, it could lead to indirect advantage by teaching subjects to rapidly explore alternative modes before committing themselves to a single response strategy.

An improved ability to supervise efficient resource allocation is one possible advantage of a good internal representation but there may be more. Internal models may not only serve the purpose of monitoring resource allocation to assure compliance to changes in task priorities, but also provide information on optimal use of resource combinations. It is possible that during the process of training and development of an internal model, subjects of the VP group may have discovered some performance combinations which were more efficient than those spontaneously adopted by the EP and NB groups. Such a possibility is especially viable under a multiple resource view of the human processing system (Gopher and Navon 1979; Wickens 1980). Within this conceptual framework the interaction between tasks and the internal model may become much more complex and diverse. Time-sharing tasks can overlap in various degrees in their demands for common resources. Thus, instead of dealing with the allocation policy of a single pool of resources, it may be necessary to combine different shares from several possible resources. Furthermore, Navon and Gopher (1979) suggest that alternative strategies can be developed for the performance of the same tasks. Hence, subjects can employ several alternative resource combinations for the performance of the same task. To continue this line of thinking, with appropriate training subjects may be able to minimize the overlap in the resource demands of the jointly performed tasks, in order to reduce the competition between them. In that case, the differences between performance which is based on a suboptimal allocation policy and performance based upon optimal allocation may be very large. The results of both our experiments strongly support this conjecture.

Although the overall pattern of differences between experimental groups was similar in both experiments, there were some differences which, we believe, stem from important differences in the nature of the two task

combinations. In the first experiment a continuous task (tracking) was concurrently performed with a self-paced discrete reaction time task (letter typing). In addition, the competition between tasks concentrated on motor-related resources (Gopher, Brickner and Navon, in press). On this task combination, training under variable priorities had strong effects on both tasks and all experimental conditions. The VP group reached superior performance levels during training, was more capable in protecting performance from difficulty changes and did better on the tracking task when simultaneously performed with a newly-introduced digit classification task. The pairing of typing with externally-paced digit classification at the end of this experiment was the first indication that this configuration may be different. When these tasks were systematically explored in experiment 2, the differences between groups were somewhat smaller and less consistent. The VP group achieved superior performance levels during practice but only on the letter typing task. In transfer to a changing difficulty manipulation the VP group obtained better performance scores only on letter typing task and did not differ from the EP group in its ability to protect performance. When transferred to the condition of typing with externally-paced digit classification, the VP group was superior to the EP group but only in the performance of the newly introduced digit task.

How can these differences be interpreted? In contrast with the first experiment, time-sharing conditions in the second experiment brought together two discrete tasks which seem to compete primarily for cognitive and memory resources. One reason for the differences between the two experiments may be related to the large mutual interference between typing and digit classification which did not seem to stem from shortage of resources. The notion of capacity interference or resource competition is reserved to

scarcity of processing facilities that can be shared in various proportions among concurrently performed tasks (Navon and Gopher 1979; Gopher and Navon 1980). In contrast, structural interference (Kahneman 1973) or concurrence cost factors (Navon and Gopher 1979; Gopher and Navon 1980) represent an all-or-none type of interference caused by factors related to incompatability between outputs, throughputs or preconditions of time-sharing tasks.

In the first experiment mutual interference between tracking and letter typing due to concurrente costs was minimal and decrements appeared to be mainly resource-relevant. A comparison of joint performance on the two tasks with their single task levels (see Figures 3 and 4) shows that single task performance was better than dual-task performance on both tasks only in an amount that can be predicted quite accurately by considering single task performance to represent a priority level of 1 and extrapolating its levels from the priority performance functions (Figure 3) or the POC curve (Figure 4). In the second experiment, in addition to the evidence for tasks competition for common resources, a strong interference factor was revealed which created a marked discontinuity between single and dual task conditions,(see Figures 9 and 10), indicating a source which is not resource-related.

This factor may account for some of the differences in the effects of experimental amnipulation in the two experiments. The variable priority manipulation is anticipated to affect performance through improving resource allocation policy. Therefore, it is predicted to affect performance only within a resource sensitive region. When a large portion of performance variability is due to irrelevant factors that increase concurrence costs, the contribution of priorities manipulation may be masked or reduced.

Another interpretation for the difference between the two experiments may be related to the relative difficulty of the concurrent tasks and to the functional relationship between task emphasis and performance. It has been shown (Gopher and Navon 1980) that the relative contribution of a priority manipulation to total performance variability is smaller in a difficult than in an easy task combination. In the present study the combination of tasks in the second experiment was probably on the average more difficult than that of the first experiment, as hinted from the better letter typing performance of subjects in the first experiment. Nevertheless, contrary to the above suggestion, priorities had large effect on performance in both experiments.

A close examination of the priority performance functions (Figures 3 and 10) reveals some differences between the two experiments. On the first experiment the effect of priorities on performance of both tasks was nearly linear (except for some non-linearity at the highest priority level of the letter typing task (Figure 3)). In the second experiment a clear effect of reduced marginal efficiency of resource investment was revealed in letter typing and its performance did not improve beyond the level of equal priorities (Figure 10). If we accept the empirical priority-performance functions as an approximation to the true performance-resource functions (PRF), we may first conclude that the PRFs of the second experiment were more complex than those of the first experiment. It was therefore more difficult to find an optimal allocation policy for each task combination. Rephrasing this argument in different words, the internal model developed during the first experiment could be simpler and more effective than the one developed in the second experiment.

A third reason for the reduced efficiency of the variable priority manipulation in the second experiment may be the constrained range of available strategies for joint performance of two discrete tasks. Damos (1977, 1980 note 2) observed three response strategies in the joint performance of discrete tasks: a parallel response strategy (the subject presses a response key in both tasks simultaneously), an alternating strategy (the subject responds first to one task then to the other) and a massed strategy (the subject emits a series of responses to one task before switching to the other). In the present experiment none of the subjects adopted a parallel response strategy: either the tasks were too difficult and their mutual interference too severe to allow such strategy, or training was not sufficient. An alternating strategy is potentially more efficient than a massed strategy, because it enables some time overlap between the tasks to occur. Massed strategy is in essence not a time-sharing strategy because the two tasks are performed singly, one at a time.

An alternating strategy tends to favor performance under equal priorities conditions because the number of responses on both tasks is about equal and simple alternation strategy can be developed. When unequal priorities are required the operator may react in one of two ways: first, he may pay more attention to one task at the expense of the other, thus performing the first task more accurately than the second task. Secondly, he may respond more often to one task than to the other, e.g., performing two letter typing reactions for each digit classification reaction. A fine-grained analysis of response strategies in experiment II is beyond the scope of this work. But, it may be speculated that changing the relative accuracy on each task may be a difficult requirement. Adapting the proportion of responses on each task to its relative priority may turn an alternating strategy into a kind of massed strategy, and lead to

equally inefficient performance. Thus, efficient utilization of variable amounts of resources may require a more complex skill of optimizing task overlap with rhythmic alternations (Keele, in press).

The concurrent performance of a continuous and a discrete task is less dependent on rhythm and timing. The tasks can more easily be performed simultaneously and the change of emphasis on one task affects the other task only to the extent that common resources are involved, with practically minimal structural interference. It seems that a variable priority training program may not be as optimal for the concurrent performance of discrete tasks. It is possible, for example, that if subjects were trained to adopt a simultaneous strategy, their overall performance could benefit more than from the present variable priority schedule (Damos 1980 note 2). In spite of the above comments, the power of the priority manipulation even in the second experiment cannot be overlooked.

The results of the two experiments demonstrate very clearly that human operators can actively control their resource allocation but apparently have only limited experience, knowledge or skill to assure the efficiency and optimality of their allocation. In the absence of relevant information and systematic instructions, spontaneous strategies may lead to suboptimal solutions. Furthermore, time-sharing performance appears to be quite rigid and lacks the flexibility to respond efficiently to fluctuations in the requirements of the situation. These skills can be considerably improved when augmented by appropriate training procedures.

The present research examined the effects of one particular training procedure on performance. However, as stated by Hirst et al (1980) the

investigation of time-sharing skills has hardly begun. This research is a small step in a long journey. Many issues remain unanswered and deserve continued research. One obvious question that stems from the present research is the persistence of these differences with prolonged training. It is clear that the 10-12 hours of practice were not sufficient to reach performance asymptotes, particularly on the second experiment. Would additional practice further strengthen the differences between the experimental groups? Would differences remain constant? Or, perhaps, diminish gradually and disappear? The outcomes of the present experiments suggest that the differences may be long-lasting or even grow further. These questions have both theoretical and practical significance.

Another important issue is the generality of the time-sharing skills acquired through priorities manipulations. What would be the generalization of training from one task combination to different types of dual-task combinations? We showed that this training technique had stronger impact on a combination of a continuous task with a self-paced discrete task, which competes mainly for motor resources, than on concurrent performance of two discrete self-paced tasks, competing for cognitive resources.

In general, positive transfer of training is expected whenever the internal model acquired during practice, or part of it, is relevant to the transfer situation. The question remains, of course, what are the rules that determine this relevance? How they related to the nature of each separate task on the one hand and to joint performance and interweaving of concurrent tasks on the other hand? The present results give us only preliminary clues to possible answers to these questions.

REFERENCE NOTES

1. Gopher, D. The skill of attention control. Paper presented at the 24th meeting of the Human Factors Society, Los Angeles, California, October 1980.

2. Damos, D.L. Response strategy and timesharing. Review of Air Force Sponsored Research, U.S. Air Force Academy, March 1980, 46-48.

REFERENCES

Adams, J.A. & Hufford, L.E. Contribution of a part-task trainer to the learning and relearning of a time-shared flight maneuver. Human Factors 1962, 2, 159-170.

Broadbent, D.E. Perception and communication. London: Pergamon Press, 1958.

Damos, D.L. Development and transfer of time-sharing skills. Aviation Research Laboratory, University of Illinois at Urbana-Champaign, ARL-77-11/AFOSR-77-10, July 1977.

Deutch, J.A. & Deutch, D. Attention: Some theoretical considerations. Psychological Review, 70, 1963, 80-90.

Duncan, J. The Locus of Interference in the Perception of Simultaneous Stimuli. Psychological Review 87, 3, 1980, 272-300.

Fleishman, E.A. The prediction of total task performance from prior practice on task components. Human Factors, 1, 18-27, 1965.

Freedle, R.O., Zavala, A. & Fleishman, E.A. Studies of the component-total task relations order of component-total task practice and total task predictability. Human Factors, 1968, 10, 283-296.

Gopher, D. & North, R.A. The measurement of attention capacity through concurrent task performance with individual difficulty levels and shifting priorities. Proceedings of the Eighteenth Annual Meeting of the Human Factors Society, Santa Monica, California, October 1974.

Gopher, D. & North, R.A. Manipulating the conditions of training in time-sharing performance. Human Factors, 1977, 19, 583-593.

Gopher, D. On the training of time-sharing skills: An attention view-point. Proceedings of the 24th annual meeting of the Human Factors Society, Los Angeles, California, October 1980.

Gopher, D., Brickner, M. & Navon, D. Different difficulty manipulations interact differently with task emphasis: Evidence for multiple resources. Journal of Experimental Psychology: Human Perception and Performance, in press.

Gopher, D. & Eilam, Z. Development of the letter-shape key board: A new approach to the design of data entry devices. Proceedings of the Human Factors Society - 23rd Annual Meeting, 1979, 40-49.

Gopher, D. & Navon, D. How Is Performance Limited: Testing the Notion of Central Capacity. Acta Psychologica, 46, 1980.

Hawkins, H.L., Rodriguez, E.R., & Gerald, M. Is Time Sharing a General Ability? Oregon University, Eugene, Technical Report, Field SE, AD A070 548, June 1979, 1-35.

Hirst, W., Spelke, E.S., Reaves, C.C., Caharack, G. & Neisser, U. Dividing attention without alternation or automaticity. Journal of Experimental Psychology: General, 1980, 109, 1, 98-117.

Holding, D.H. Knowledge of Results (1965). In Legge, D. (Ed.), Skills, Penguin Modern Psychology Readings, 1970, 249-265.

Jennings, A.E. & Chiles, W.D. An investigation of time-sharing ability as a factor in complex performance. Human Factors, 1977, 19, 535-548.

Johnston, W.A., Griffith, D. & Wagstaff, R. Speed, accuracy and ease of recall. Journal of Verbal Learning and Verbal Behavior, 1972, 11 512-520.

Keele, S.W. Behavioral Analysis of Movement. In: Brooks, V. (Ed.), Handbook of Physiology: Volume on Motor Control (in press).

Kahneman, D. Attention and effort. Englewood Cliffs, N.J.: Prentice-Hall, 1973.

Kalsbick, J.W.H. & Sykes, R.N. Objective measurement of mental load. In: A.F. Sanders (Ed.), Attention and Performance, Amsterdam, 253-261, 1967.

Kerr, B. Processing demands during mental operations. Memory and Cognition 1973, 1, 401-412.

Kessel, C., & Wickens, C.D. Development and utilization of internal models in dynamic systems, a comparison of monitors and operators as failure detectors. University of Illinois at Urbana-Champaign, Tech. Rep. ELP-78-2/AFOSR-78-5, December 1978.

Logan, G.D. Attention in character classification tasks: Evidence for the automaticity of component stages. Journal of Experimental Psychology: General, 1978, 107, 32-63.

Logan, G.D. On the Use of a Concurrent Memory Load to Measure Attention and Automaticity. Journal of Experimental Psychology: Human Perception and Performance, 1979, 5, 189-253.

Logan, D.L. Attention, automaticity and the ability to stop a speeded choice response. In: J. Long & A.D. Baddeley (Eds.), Attention and Performance, Hillsdale, N.J.: Erlbaum, 1981.

Michon, J.A. Tapping regularity as a measure of perceptual motor load. Ergonomics, 1966, 9, 401-412.

Moray, N. Where is capacity limited? A survey and a model. Acta Psychologica, 1967, 27, 84-92.

Navon, D. & Gopher, D. On the Economy of the Human Processing System. Psychological Review, 1979, 86, 214-253.

Navon, D. & Gopher, D. Task Difficulty, Resources and Dual Task Performance. In: Nickerson, R.S. (Ed.), Attention and Performance VIII, Laurence Erlbaum and Associates, 1980, chap. 15, 297-315.

Navon, D., Gopher, D. & Chillag, N. Does dual-axis tracking demand more resources than single axis tracking? Technion - Israel Institute of Technology, Tech. Report AFOSR-80-1, February 1980.

Neisser, U. Cognition and reality. San Francisco, Freeman, 1976.

Norman, D.A. & Bobrow, D.J. On data-limited and resource-limited processes. Cognitive Psychology, 1975, 7, 44-64.

Norman, D.A. & Bobrow, D.J. On the analysis of performance operating characteristics. Psycholgoical Review, 1976, 83, 508-510.

North, R.A. Task component and demands as factors in dual-task performance. University of Illinois at Urbana-Champaign, Aviation Research Lab. ARL-77-2/AFOSR-77-2, 1977.

Ogden, G., Levine, J. & Eisner, E. Measurement of workload by secondary tasks. Human Factors, 1979, 21 (5), 529-548.

Ostray, D., Moray, N. & Marks, G. Attention practice and semantic targets. Journal of Experimental Psychology: Human Perception and Performance, 1976, 2, 326-336.

Pew, R.W. Human Perceptual-Motor Performance. In: B.H. Kantowitz (Ed.), Human Information Processing: Tutorials in Performance and Cognition, Laurence Erlbaum Associates, 1974.

Posner, M.I. & Snyder, C.R.R. Attention and cognitive control. In: R. Solso, (Ed.), Information processing and cognition: The Loyola Symposium. Hillsdale, N.J.: Erlbaum, 1975 (a).

Posner, M.I. & Boies, S.W. Components of attention. Psychological Review, 1971, 78, 391-408.

Rieck, A M., Ogden, G.D. & Anderson, N.S. An investigation of varying amounts of component-task practice on dual-task perfommance. Human Factors, 22, 3, 1980, 373-384.

Rolfe, J.M. The secondary task as a measure of mental load. In: W.T. Singleton, R.S. Easterby & D.E. Whitfield (Eds.), Measurement of man at work. London: Taylor & Francis, 1971.

Schneider, W. & Shiffrin, R.M. Controlled and automatic human information processing: I. Detection, search and attention. Psychological Review, 1977, 84, 1-66.

Shiffrin, R.M. The locus and role of attention in memory systems. In: P.M.A. Rabbit & S. Dornic (Eds.), Attention and Performance V. London: Academic Press, 1975.

Shiffrin, R.M. & Schneider, W. Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. Psychological Review, 1977, 84, 127-190.

Spelke, E.S., Hirst, W.C. & Neisser, U. Skills of divided attention. Cognition, 1976, 4, 215-230.

Sperling, G. & Melchner, M.J. The attention operating characteristic: Examples from visual search. Science, 1978, 202, 315-318 (a).

Sperling, G. & Melchner, M. Visual search, visual attention and the attention operating characteristic. In: J. Requin (Ed.), Attention and Performance VII. New York: Academic Press, 1978 (b).

Stroop, J.R. Studies of interference in serial verbal reactions. Journal of Experimental Psychology, 1935, 18, 643-662.

Sverko, B. Individual differences in time-sharing performance. Technical Report ARL-77-4/AFOSR-77-4, Aviation Research Laboratory, January 1977.

Treisman, A.M. Strategies and models of selective attention. Psychological Review, 1969, 76, 282-299.

Trumbo, D. & Noble, M. Secondary effects on serial verbal learning. J. of Experimental Psychology, 85, 418-424, 1970.

Welford, A.T. Fundamentals of skill. London: Methuen, 1968.

Welford, A.T. Mental workload as a function of demand capacity, strategy and skill. Ergonomics, 21 (3), 151-157, 1978.

Underwood, G. Moray vs. the rest: The effects of extended shadowing practice. Quarterly Journal of Experimental Psychology, 1974, 26, 368-372.

Wickens, C.D. Human failure detection, attention and resource allocation in dynamic environments. Final Report. University of Illinois at Urbana-Champaign, EPL-70-2/AFOSR-79-2, February 1979.

Wickens, C.D. The structure of processing resources. In: R. Nickerson & R. Pew (Eds.), Attention and Performance VIII. New York: Erlbaum, 1980.

Wickens, C.D. & Gopher, D. Control theory measures of tracking as indices of attention allocation strategies. Human Factors, 1977, 19, 349-365.

Wickens, C.D. & Kessel, C. The effect of participatory mode and task workload on the detection of dynamic system failures. IEEE Transactions on System, Man and Cybernetics, 1979, 13, 24-31 (a).

Wickens, C.D. & Kessel, C. The processing resource demands of failure detection in dynamic systems. Journal of Experimental Psychology: Human Perception and Performance, 1980, 564-577.

Wickens, C.D. & Kessel, C. Human detection and diagnosis of system failures. In: J. Rasmussen & W.B. Rouse (Eds.), New York: Plenum Press, 1981.

Veldhysen, W. & Stassen, H.G. The internal model: What does it mean in human control? In: T.B. Sheridan & G. Johnsen (Eds.), Monitoring Behavior and Supervisory Control. New York: Plenum Press, 1976.

Woodhead, M.M. An effect of noise on the distribution of attention. Journal of Applied Psychology, 1966, 50, 296-299.

Zavala, A. & Geist, A.M. Component-total task relationships: Simple and sequential practice effects. Human Factors, 1968, 10, 333-344.

APPENDIX A

Sets of letters for the letter typing task:-

4 Easy Letters

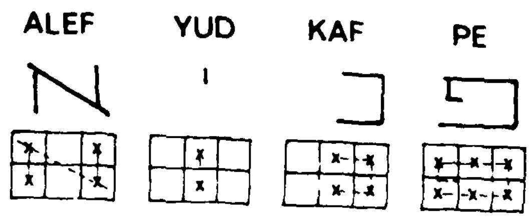
English phonetic equivalent

Hebrew letter

Strokes

Letter shape code A

B



4 Medium Difficult Letters

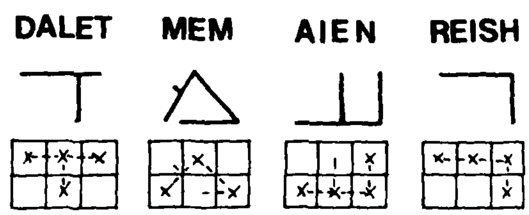
English phonetic equivalent

Hebrew letter

Strokes

Letter shape code A

B



4 Difficult Letters

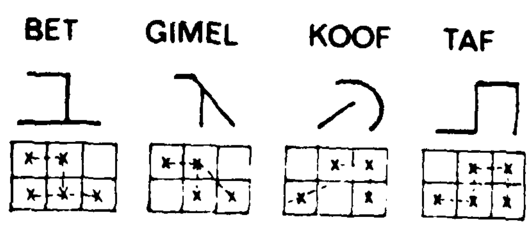
English phonetic equivalent

Hebrew letter

Strokes

Letter shape code A

B



The three mixed letter shets were:

(a)	BET	YUD	MEM	RESH
(b)	KAF	AIEN	PE	KUF
(c)	ALEF	GIMEL	DALETH	TAF

FILMED

9-8